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REPORT OF INVESTIGATIONS—NO. 143

PETROGRAPHIC ANALYSIS OF COAL BY THE PARTICLE COUNT METHOD

By
BRYAN C. PARKS

Reprinted from Economic Geology, Volume 44, pp. 376–424, 1949

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Topographic Mapping in Cooperation with the United States Geological Survey.

This report is a contribution of the Coal Division.

June 1, 1949

Reprinted from ECONOMIC GEOLOGY, Vol. 44, No. 5, August, 1949
Printed in U. S. A.

PETROGRAPHIC ANALYSIS OF COAL BY THE PARTICLE COUNT METHOD.[1]

BRYAN C. PARKS.

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ABSTRACT.

Quantitative determinations were made of the banded ingredient composition of a number of domestic stoker coals prepared for combustion tests from large lot samples of small-size coal procured at 15 Illinois coal mines. The determinations were made by identifying and counting the discrete coal particles in selected samples using the petrographic technique which is commonly used to assay performance in ore dressing operations.

A standard procedure for the analysis was developed which included close control of all steps in selecting the sample, crushing to free coal components into discrete particles, and size classifying the particles by mechanical screening. Strict criteria were adopted for identifying the coal particles.

The results of the petrographic analyses which were of special interest in connection with the combustion tests concerned the effect of coal cleaning processes upon the proportion of banded ingredients. An increase in vitrain content of the cleaned coal was usually noted but concentration of this ingredient was never of considerable amount. The analyses also showed there was no great concentration of vitrain in the lots of small-size coal secured from the mines. Previously it had been thought that vitrain by virtue of its friable nature constituted a major proportion of the "screenings" produced in coal mining and preparation.

During the course of the work certain incidental investigations were carried on concerning the effect of differences in hardness of the banded ingredients on size distribution when more or less "pure" ingredients were crushed under controlled conditions. The variation in specific gravity of the banded ingredients and the effect of this variable property in separating or concentrating coal ingredients by use of heavy liquid media was investigated. The paper discusses reliability of this method of petrographic analysis of coal and reports certain experiments made to determine degree of accuracy achieved.

SUMMARY.

Petrographic analysis of coal provides information concerning its ingredient composition in terms of vitrain, clarain, durain, fusain, and mineral matter. Lumps and columns of coal are analyzed by making profile or vertical measurements normal to the banding of polished surfaces. It is more difficult to analyze broken coal but it can be done by using conventional petrographic methods of rock analysis or by particle count, using methods employed in ore preparation and in other fields. The results of analysis, by particle count, of a group of small size broken coals used in stoker tests are herein reported.

The coals, which were generally screenings as obtained from the mines, were sized to ½-inch by 8-mesh for the combustion tests (one exception).

A series of three combustion tests was generally made on each coal. These were on the (1) unwashed coal, (2) a washed coal prepared by tabling in a normal manner, and (3) a washed coal with a mineral matter content lower than commercially reasonable.

For the particle count method, the samples were crushed to pass an 8-mesh screen. The demarcation between vitrain and microvitrain, the latter a component of clarain, was regarded as 1/10-inch.

Exploratory analyses made by the Illinois Geological Survey about 1936 indicated that coal preparation processes caused material changes in the proportions of the banded ingredients in the coals tested, up to the point where as much as one-half to two-thirds of some coal samples consisted of vitrain. It was thought that such high concentrations of vitrain, or even much smaller concentrations, would have pronounced effects upon the combustion characteristics of the coal when used in stokers. The preparation in the present tests was expected to cause considerable concentration of the ingredients. The maximum concentration of vitrain, however, was only about 30 percent. The vitrain content in several of the washed coals did not exceed 10 percent. In one case it was as low as 2 percent. These results were unexpected, but were obtained after improved analytical technique had been developed as the result of investigation along four lines of inquiry:

1. As one of the difficulties of analysis and a possible source of error lay in determining the ingredient composition of the very fine sizes of coal, it was desirable to develop a satisfactory technique which would reduce to a minimum the quantity of such a size. A method involving the crushing of the coal through rolls was finally adopted.

2. A further source of error consisted in the unknown extent to which microvitrain, which is one of the common components of clarain, contributed to the material classified as vitrain in the analyses, that is to the "analytical vitrain." The yield of analytical vitrain from coal containing no vitrain bands (thickness 1/10-inch or more) was therefore studied and found to be less than 6.9 percent of samples tested and to be limited chiefly to the very small screen sizes, generally smaller than 28-mesh. Reduction of the amount of this very fine material by careful crushing lessened the importance of this factor of error.

3. Although the amount of fine coal could be considerably reduced by careful handling, an important quantity remained and a knowledge of its character was essential to accurate measurement. Also its very fine size made quantitative measurement by counting disproportionately laborious. Systematic investigation of size distribution of the banded ingredients in crushed coal revealed that definite relations existed between size distribution of each of the banded ingredients and that of the sample as a whole. Accordingly, by the use of a special curve of size distribution, it was found possible to estimate closely the quantity of each ingredient present in the small screen sizes, once such quantities were determined for three or four of the larger screen sizes. Thus labor, time used, and the probability of error were greatly reduced.

4. The amount of segregation caused in cleaning the coals used in the stoker tests was investigated. Experiments revealed inconsistency in the behavior of the broken coal in float-and-sink liquids, showing particularly that vitrain did not systematically concentrate in the low-gravity fractions in spite of the fact that the lightest individual fraction of the coal tended to be vitrain. Concentration appeared to be significant only when the gravity of the separation fluid approached the minimum specific gravity of the vitrain. These tests provided a reasonable explanation for the low vitrain concentration reported in the particular stoker coals analyzed.

INTRODUCTION.

Plan of the Report.—This report describes a method of physical (petrographic) analysis of broken coal in terms of the banded ingredients, particularly vitrain and clarain, applied to a group of Illinois coals used in combustion tests in an underfeed domestic-type stoker attached to a hot-water boiler.[2] The report also gives the petrographic analyses of the coals. It describes additional tests, to establish the validity of certain details of the analytical procedure and to explore the effectiveness of the cleaning practices used in segregating the ingredients into the various size and gravity fractions, as applied to these particular coal samples. No effort was made to explore the possibilities of producing from Illinois coal prepared coal with a high single-ingredient content. Petrographic analysis of any coal is possible by using the method here described.

Coal Ingredients.—The banded ingredients of coal—vitrain, clarain, durain, fusain, and mineral matter—have been described in earlier Survey publications.[3] The criteria of banded ingredient identification are given in Table 1.

Vitrain bands (Figs. 1 and 2) as thick as three inches have been observed in Illinois coal; thinner bands occur. Those of microscopic size are referred to as microvitrain, which is a common component of most clarain. Clarain is the major ingredient of Illinois coal, commonly making up 70 percent or more of the beds. Its prime diagnostic characteristic is a distinctly laminated structure which, in the brighter clarain, produces a silky luster. The brightness and silkiness of luster of clarain increase with the amount of microvitrain present.

No standard of band width has been adopted for differentiating vitrain and microvitrain. Stopes,[4] working with British coals, suggested that vitrain occurs in layers commonly ranging from 2 mm to 8 mm thick. Cady [5] at first suggested that for Illinois coals the minimum thickness of vitrain should

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[2] Helfinstine, Roy J., and Boley, Charles C., Correlation of domestic stoker combustion with laboratory tests and types of fuels. II. Combustion tests and preparation studies of representative Illinois Coals: Illinois Geol. Survey Rept. Inv. 120, 1946.

[3] Cady, Gilbert H., Nomenclature of the megascopic description of Illinois coal: Illinois Geol. Survey Circ. 46, 1939.

[4] Stopes, Marie C., On the four visible ingredients in banded bituminous coals: Studies in the composition of coal: Royal Soc. London Proc., vol. 40, p. 470, 1919.

[5] Cady, Gilbert H.. The physical constitution of Illinois coal and its significance in regard to utilization: Illinois Mining Inst. Proc., p. 6, 1933.

TABLE 1.

Classification and Description of the Banded Ingredients.

Banded ingredients	Classification of banding	Range of thicknesses	Distinguishing criteria for identification of the banded ingredients		
			Characteristics of bed-coal and lumps	Characteristics of small particles—1/10″ dimension	Characteristics of polished surfaces
Vitrain	Coarse bands	+1/10″ (+2 mm)	Bands jet, glossy, black; smooth textured; conchoidal fractures; often prominent vertical fractures filled with mineral matter in the thicker layers, brittle.	Irregular particles tending to be lense shaped, conchoidal fracture, thin edges; black to grayish; brilliant luster, smooth textured. At low magnification thin edges often show orange colored translucency, also the entire particles in very fine sizes.	Jet to grayish black, homogeneous texture, brilliant luster, high reflectance.
	Fine bands	1/10″ to 1/50″ (2 to 0.5 mm)			
	Micro bands	−1/50″ (−0.5 mm)			
Clarain	Fine banded	1/10″ to 1/50″ (2 to 0.5 mm)	Bright to grayish, streaked or silky lustered, fracture uneven and conchoidal, harder than vitrain but sometimes brittle.	Irregular shaped particles, less lenticular than vitrain but some showing conchoidal fracture, streaked appearance characteristic of all particles larger than 1/50″, smaller particles show only a varying proportion of dull coal attached to vitreous coal.	Bright, streaked and silky lustered, sometimes dullish gray.
	Micro banded	−1/50″ (−0.5 mm)			
Durain	Coarse bands	+1/10″ (+2 mm)	Dull grayish, even textured, mat surface, grainy fracture, hard.	Particles tend to be platy shaped with fracture planes nearly at right angles in larger particles, grainy surface, dull gray, small particles very irregular and grainy, often with spores and rodlets imbedded in surface.	Dull gray, even mat textured.
	Fine bands	−1/10″ (−2 mm)			
Fusain	Coarse bands and lenses	+1/10″ (+2 mm)	Jet black to grayish black, sometimes brilliant; often has loose splintery appearance; usually very soft but sometimes firmly cemented with mineral matter.	Needle and platy shaped particles jet black, grayish, and sometimes brilliant; surface punctate showing evidence of cellular structure; usually very soft and powdery but sometimes hard and brittle.	Dark gray, porous.
	Fine bands	−1/10″ (−2 mm)			

be established as 1/16-inch but later was of the opinion that there was practical justification in placing the limit at about 0.1-inch or approximately 2 mm.[6] McCabe [7] and others, measuring columnar sections, limited the measurement of vitrain to bands plus 0.5 mm or about 0.02-inch thick. In this investigation the minimum width of vitrain bands was regarded as 0.1-inch in accordance with the tentative definition of Cady in 1938, although megascopic identification of the material is possible to about the minimum of 0.02-inch. The modification of the analytical values on the basis of a minimum thickness 0.02-inch is considered in a later part of this report.

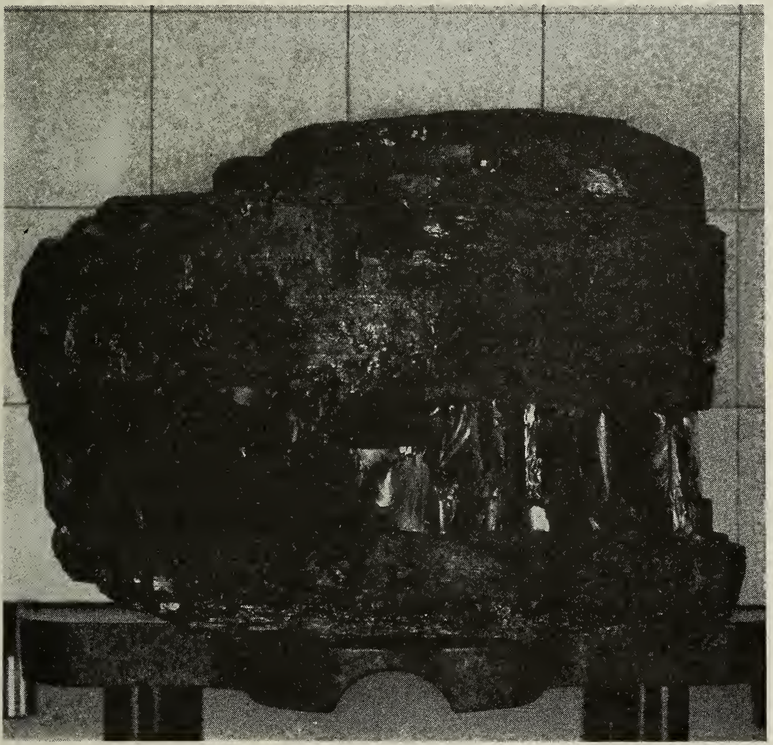

FIG. 1. A lump of Indiana bituminous coal showing clarain above, a thick band of vitrain (glossy), followed by fusain, with clarain at the bottom. Background shows two-inch squares.

The bright luster of clarain diminishes with decrease in the content of microvitrain, and it passes more or less imperceptibly into a dull grayish coal, known as *durain,* with a mat or lusterless surface. There is megascopically no clear distinction between clarain and durain; durain, however, is characterized microscopically by the presence of opaque matter and a general absence of microvitrain. Cannel coal is regarded as a variety of durain in which a large part of the coal consists of plant spores. Certain cannel-like coals of very fine texture and silky luster, however, are composed predominately of extremely thin, closely packed sheets of microvitrain. On the whole, durain and cannel coal are very minor constituents of Illinois coals. Bands of coal of a grayish tint and dull luster, suspected of being durain, commonly contain much mineral matter. Durain (Fig. 3) in Illinois coals is difficult to identify except in thin sections because of the similarity of bands of durain and layers of bony coal or other coal with a high mineral matter content.

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[6] Cady, Gilbert H., Modern concepts of the physical constitution of coal: Jour. Geology, vol. 50, no. 4, pp. 337–356, May–June, 1942.

[7] McCabe, L. C., Concentration of the banded ingredients of Illinois coals by screen sizing and washing: A.I.M.E., Tech. Paper No. 684, 1936.

The fourth ingredient of coal is fusain, or mineral charcoal, which has the general appearance of charcoal. It occurs partly as thin layers among the other ingredients and partly as small particles disseminated in clarain and durain. Most of the fusain that was originally present in the coal used in the stoker tests was eliminated during preparation; hence this ingredient is unimportant in these investigations.

Because the properties of the ingredients differ, the relative quantity of the individual ingredients composing a coal may be of significance in its utilization. Investigation of this possibility was one of the objectives of a series of stoker-boiler tests on a variety of Illinois coals, so prepared that selective segregation of the ingredients seemed possible.

Acknowledgments.—The author gratefully acknowledges the help of H. L. Smith, formerly Assistant Geologist of the Coal Division of the Illinois Geological Survey, who assisted in the preparation of many of the samples for microscopic analysis. C. C. Boley, formerly Mining Engineer, and R. J. Helfinstine, Mechanical Engineer, of the Coal Division staff, have given generously of their time and thought in discussions of many problems. G. H. Cady, Senior Geologist and Head of the Coal Division, supervised the work and gave generous assistance and advice in the preparation of the report.

PETROGRAPHIC ANALYSIS OF BED COAL AND OF BROKEN COAL.

Analysis of Bed Coal by Profile Measurement.

Lumps or bed-columns of coal or diamond-drill cores of coal beds can be fairly easily analyzed in terms of the banded ingredients by visual inspection of polished surfaces. The character and width of individual bands are recorded serially by profile measurement normal to the bedding. The method is similar to that used in making a record of strata penetrated in drilling, but on a much smaller scale.

This study did not include an investigation of the amount of banded ingredients present in the bed coal from which the samples were derived; however, this had been done previously for coal beds in several parts of the State[8] (Table 2).

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[8] McCabe, L. C., Mitchell, D. R., and Cady, G. H., Banded ingredients of No. 6 coal and their heating values as related to washability characteristics: Illinois Geol. Survey Rept. Inv. 34, p. 14, table 2, 1934.

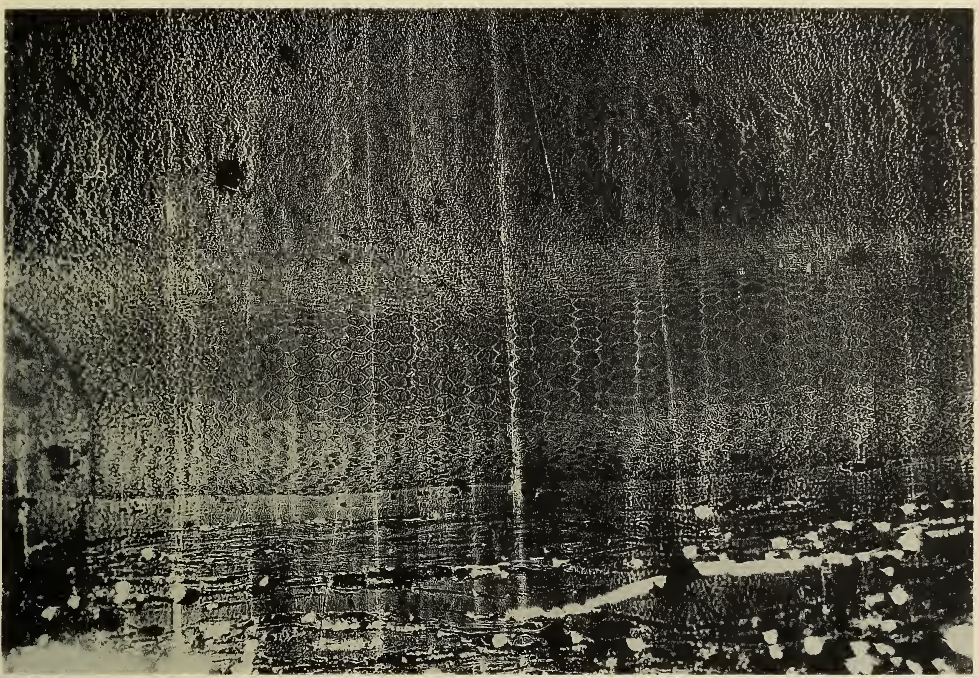

FIG. 2. Thin section of coal with vitrain showing cell structure. (Lower part is clarain.) No. 6 coal, Winkle mine, Perry Co., Ill.

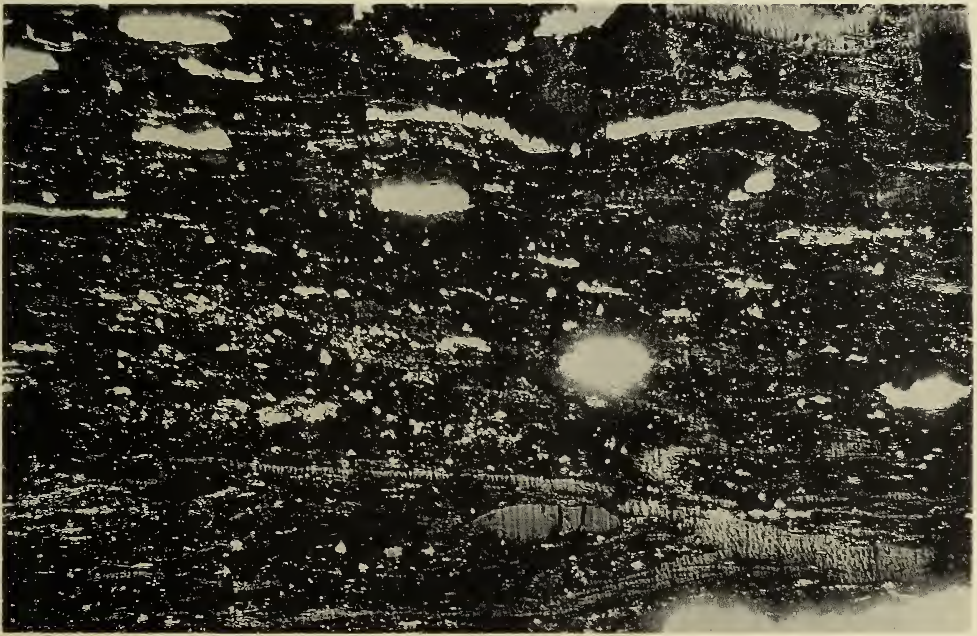

FIG. 3. Thin section of coal; mainly opaque matter (durain). No. 6 coal, Nashville mine, Washington Co., Ill.

TABLE 2.

Percentages of Banded Ingredients in Columnar Sections of Coal Beds 2, 5, and 6.

Each Value Represents an Average of Two Determinations.

Coal bed no.	County V+C	Banded coal ingredients				Banded impurities		
		Vitrain	Clarain	Durain	Fusain	Pyrite	Bone	Clay
2	Fulton 96.3	17.75	78.52		0.56	2.05		1.12
5	Saline 96	26.60	69.30		1.80	2.30		
6	St. Clair 89.7	13.16	76.51		3.38	5.12		1.83
	St. Clair 90.9	7.83	83.09		2.62	4.76		1.70
	St. Clair 87.5	9.95	77.58		7.43	1.82	1.33	1.89
	Montgomery 81.6	19.5	62.1	14.9	0.8	1.5		1.2
	Washington 82.1	13.40	68.70	15.0	2.9			[a]
	Randolph 90.6	14.76	75.88		4.77			4.59
	Perry 88.9	19.00	69.90		4.50		2.6	4.00
	Franklin 96.5	18.81	77.68		1.50	0.42	0.61	0.98
	Franklin 95.1	22.70	72.40		2.3	0.10	1.60	0.9
	Williamson 96.7	20.10	76.55		1.35		2.0	

av 90% — V+C

[a] Eight-inch clay band removed in mining.

It will be noted that the vitrain content of these coals ranges from 7.83 to 26.6 percent in the bed. Examination of other columns and cores of Illinois coal beds showed that the vitrain content was as much as 24 percent of the bed. Fusain ranges in amount from 0.56 to 7.43 percent and the amount of durain is generally less than 2 percent.[9] Clarain composes very much the largest portion of the coal. No distinction was made between the bright and the gray varieties of clarain.

Analysis of Broken Coal.

General Methods.—The technique of petrographic analysis of broken coal is determined by the fragmentary character and the small size of the material. The most desirable product for microscopic count consists of a small amount of particles which are representative in composition and in which the ingredients are uniformly distributed, permitting the most accurate determinations with the fewest particles counted. Careful sampling is very important.

Two methods of making quantitative determinations of each banded ingredient in broken coal have been used: By measuring their proportional volumes, and by counting particles to obtain proportional numerical percentages. Volumetric measurement of coal ingredients may be made on a polished surface of a disc of plastic material in which coal fragments are mounted. Linear traverses with a microscope having an ocular measuring accessory are made in such manner and in sufficient number to secure volumetric estimates of each ingredient. The linear measurements are accumulated mechanically by an integrating microscope stage. This method has been used frequently in Germany.

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[9] McCabe et al. (Table 2) reported durain in only two samples: Montgomery County 14.9 percent, and Washington County 15.0 percent. These values for durain are very high for Illinois coal and the identification of at least some of the bands of bone coal as durain is possible. However, the No. 6 coal in Washington County is known to contain more than the usual amount of durain or splint coal (Fig. 3) found in Illinois coals.

The mineral ingredient composition of a crushed ore is commonly determined by counting particles, using an ore-dressing microscope. The same procedure is applicable to the analysis of broken coal. It requires careful sampling, close sizing by sieving, and manual separation and counting of the constituents in the sample. The numerical count of individual particles is converted to percentage estimates of the ingredients by appropriate weighting of the results. The method has been used for a number of years in the examination of broken coal by the Illinois Geological Survey.[10]

Ingredient analysis of the coals by the particle count method was somewhat simplified because in the preparation of the original sample for the stoker tests, all coal less than 8-mesh in size was mainly eliminated, whether this was minus 8-mesh coal in the sample as obtained at the mine or was that produced in crushing the coal in the laboratory. This automatically eliminated a large proportion of the fusain, both that part which originated in layers and lenses and the much smaller quantity occurring as disseminated particles, particularly in the clarain. Fusain offers no serious identification difficulty except when it is extremely fine. Furthermore, the amount of durain or splint coal was very small and not important in any of the coals examined. The problem, therefore, became largely one of differentiating the clarain, particularly the bright clarain, and the vitrain.

The differentiation of clarain and vitrain presented two difficulties: One was the actual recognition of striated clarain in fragments less than 0.1-inch in diameter, and particularly in fragments much less than this size down to about 100-mesh; the other was the differentiation of vitrain and microvitrain.

The recognition of striated structure in fine particles of bright coal depends upon the development of judgment and skill on the part of the operator and the use of somewhat higher magnification than is generally necessary for megascopic identification. The results on the same sample by two trained operators usually checked very closely on the vitrain and clarain content.

Identification of Vitrain and Microvitrain.—Vitrain and microvitrain in clarain have no fundamental differences. Practical solution to the problem of differentiating these substances quantitatively was reached by experimental study of the distribution of banded ingredients in coal crushed to desired sizes.

Attention may be first directed to the determination of vitrain content of the coal and then to the possible errors involved in this determination. On the assumption that the band thickness of vitrain must be 0.1-inch or more, the coal sample was crushed to pass 8-mesh (0.093-inch). This broke up all of the vitrain bands, although undoubtedly not all of it was freed into discrete particles. The preponderant concentration of the crushed coal in relatively large size fragments, commonly more than 70 percent plus 28-mesh (0.02-inch) (Table 3), decreased the probability of microvitrain being freed

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[10] McCabe, L. C., Concentration of the banded ingredients of Illinois coals by screening, sizing, and washing: A.I.M.E. Tech. Paper 684, 1936.

TABLE 3.

Screen Analyses of Hand-Crushed and of Roll-Crushed Samples of Vitrain, Clarain, Durain, and Mixed Coal.

Screens	(1) Vitrain		(2) Vitrain		(3) Vitrain		(4) Clarain		(5) Clarain		(6) Clarain		(7) Durain	
	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %
8×10	49.7	49.7	21.7	21.7	41.6	41.6	25.1	25.1	42.7	42.7	36.3	36.3	36.1	36.1
10×14	19.3	69.0	27.4	49.1	22.2	63.8	20.0	45.1	19.1	61.8	22.0	58.3	24.7	60.8
14×20	11.1	80.1	17.2	66.3	12.6	76.4	14.4	59.5	11.6	73.4	13.0	71.3	14.2	75.0
20×28	6.6	86.7	11.4	77.7	8.0	84.4	9.9	69.4	7.5	80.9	8.9	80.2	8.2	83.2
28×35	4.6	91.3	7.7	85.4	5.2	89.6	8.0	77.4	5.3	86.2	6.0	86.2	5.6	88.8
35×48	3.0	94.3	5.1	90.5	3.8	93.4	6.2	83.6	4.2	90.4	4.6	90.8	4.1	92.9
48×65	2.3	96.6	4.0	94.5	2.8	96.2	5.3	88.9	3.4	93.8	3.5	94.3	2.8	95.7
65×100	1.6	98.2	2.4	96.9	1.8	98.0	4.1	93.0	2.5	96.3	2.5	96.8	1.3	97.5
100×150	0.8	99.0	1.5	98.4	1.0	99.0	2.8	95.8	1.4	97.7	1.3	98.1	1.0	98.5
150×200	0.7	99.7	0.9	99.3	0.8	99.8	1.8	97.6	1.4	99.1	1.2	99.3	0.8	99.3
200×300	0.2	99.9	0.3	99.6	0.18	99.98	0.7	98.3	0.4	99.5	0.4	99.8	0.3	99.6
−300	0.1	100.0	0.4	100.0	0.12	100.0	1.7	100.0	0.5	100.0	0.2	100.0	0.4	100.0

Screens	(8) Mostly clarain		(9) Mixed		(10) Mixed		(11) Mixed		(12) Mixed		(13) Vitrain	
	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %
8×10	25.4	25.4	22.7	22.7	21.0	21.0	38.4	38.4	—	—	22.5	22.5
10×14	20.0	45.4	24.7	47.4	25.5	46.5	18.5	56.9	—	—	25.5	48.0
14×20	14.5	59.9	15.6	63.0	17.0	63.5	9.3	66.2	—	—	16.5	64.5
20×28	10.4	70.3	10.7	73.7	11.0	74.5	7.0	73.2	—	—	12.0	76.5
28×35	7.4	77.7	7.4	81.1	7.8	82.3	5.3	78.5	34.5	34.5	9.5	86.0
35×48	6.2	83.9	5.7	86.8	5.9	88.2	4.6	83.1	22.3	56.8	5.5	91.5
48×65	4.9	88.8	4.5	91.3	4.4	92.6	3.4	86.5	15.2	72.0	3.8	95.3
65×100	3.8	92.6	3.4	94.7	3.0	95.6	3.0	89.5	10.9	83.9	2.3	97.6
100×150	2.7	95.3	1.9	96.6	1.7	97.3	1.8	91.3	5.9	88.8	1.4	99.0
150×200	1.7	97.0	1.9	98.5	1.5	98.8	2.0	93.3	5.6	94.4	0.6	99.6
200×300	0.7	97.7	0.7	99.1	0.5	99.4	1.1	94.4	1.7	96.1	0.2	99.8
−300	2.3	100.0	0.9	100.0	0.6	100.0	5.6	100.0	3.9	100.0	0.2	100.0

(1) Selected vitrain crushed with roll-crusher to pass 8-mesh.
(2) Selected vitrain crushed with roll-crusher to pass 8-mesh.
(3) Selected vitrain crushed with mortar and pestle to pass 8-mesh.
(4) Selected clarain crushed with roll-crusher to pass 8-mesh.
(5) Selected clarain crushed with roll-crusher to pass 8-mesh.
(6) Selected clarain crushed with mortar and pestle to pass 8-mesh.
(7) Selected durain crushed with roll-crusher to pass 8-mesh.
(8) Selected coal, mostly clarain but with vitrain bands from 1 to 2.5 mm thick, crushed with roll-crusher to pass 8-mesh.
(9) $1\frac{1}{2}$ by $\frac{1}{2}$-inch mixed coal crushed with roll-crusher to pass 8-mesh.
(10) $\frac{1}{2}$-inch by 8-mesh mixed coal crushed with roll-crusher to pass 8-mesh.
(11) Minus 8-mesh mixed coal from $1\frac{1}{2}$-inch mine screenings—breakage from mining and preparation only.
(12) 8 by 10-mesh mixed coal crushed with roll-crusher to pass 28-mesh.
(13) Distribution of vitrain in a crushed sample of mixed coal as determined by petrographic analysis.

from crushed clarain, but undoubtedly some microvitrain bands less than 0.1-inch thick were broken. The counting of vitrain was eventually restricted to material 8 by 28-mesh. All vitrain-like particles (particles strictly fulfilling the criteria requirements) were assigned to vitrain, thus providing the amount of "analytical" vitrain, or the vitrain represented by the analytical value, which may be larger (but is never smaller) than the amount of vitrain actually present. The inclusion of some microvitrain in the count of analytical vitrain introduced a small error which may have been partly compensated by incomplete freeing of plus-0.1-inch vitrain.

TABLE 4.

AMOUNT AND SIZE DISTRIBUTION OF ANALYTICAL VITRAIN OBTAINED BY CRUSHING THREE SELECTED SAMPLES OF CLARAIN WITH WIDE, MEDIUM, AND NARROW BANDS OF MICROVITRAIN RESPECTIVELY.

Screen size	(1)				(2)				(3)			
	Coal retained on screens, grams	Clarain	Vitrain		Coal retained on screens, grams	Clarain	Vitrain		Coal retained on screens, grams	Clarain	Vitrain	
		%	%	Cumulative %		%	%	Cumulative %		%	%	Cumulative %
8×10	12.15	98.0	2.0	11.4	25.4	99.5	0.5	1.9	42.7	100	—	—
10×14	7.37	97.0	3.0	21.8	20.0	97.5	2.5	9.3	19.1	100	—	—
14×20	4.34	95.0	5.0	32.1	14.5	96.0	4.0	17.9	11.6	99.5	0.5	4.5
20×28	2.99	92.0	8.0	43.3	10.4	93.5	6.5	27.9	7.5	99.0	1.0	10.4
28×35	2.01	88.5	11.5	54.2	7.4	89.6	10.4	39.3	5.3	98.0	2.0	18.6
35×48	1.54	85.0	15.0	65.0	6.2	85.0	15.0	53.1	4.2	97.0	3.0	28.5
48×65	1.17	80.0	20.0	76.0	4.9	79.5	20.5	68.0	3.4	95.0	5.0	41.7
65×100	0.82	75.0	25.0	85.7	3.8	73.0	27.0	81.5	2.5	92.0	8.0	57.3
100×150	0.56	73.0	27.0	92.8	2.7	65.0	35.0	91.9	1.4	88.0	12.0	70.4
150×200	0.30	70.0	30.0	97.0	1.7	63.0	37.0	97.9	1.4	84.0	16.0	87.8
200×300	0.13	68.0	32.0	99.0	0.7	64.0	36.0	100.0	0.4	85.0	15.0	92.5
−300	0.07	75.0	25.0	100.0	—	—	—	—	0.6	84.0	16.0	100.0
	Total analytical vitrain in sample of clarain crushed to pass 8-mesh, 6.30%.				Total analytical vitrain in sample of clarain crushed to pass 8-mesh, 6.91%.				Total analytical vitrain in sample of clarain crushed to pass 8-mesh, 1.3%.			
	Analytical vitrain 8×28-mesh, 2.75% of sample.				Analytical vitrain 8×28-mesh, 1.93% of sample.				Analytical vitrain 8×28-mesh, .14% of sample.			

(1) Bright clarain with bands of microvitrain of approximately 1/10-inch maximum width.
(2) Bright clarain with bands of microvitrain of approximately 1/25-inch maximum width.
(3) Bright clarain with bands of microvitrain of approximately 1/50-inch maximum width.

The amount of error resulting from inclusion of microvitrain in the analytical vitrain was investigated (Table 4). Tests with clarain that had microvitrain near the maximum width, 0.1-inch, indicated, for the particular samples used, that less than 2.75 percent of the clarain when crushed, was represented by discrete particles of microvitrain in sizes 8 by 28-mesh. The tests with this clarain, which in crushing probably yielded about the maximum 8 by 28-mesh microvitrain, indicate that for any coal containing much microvitrain near the maximum width, the determined amount of analytical vitrain will be higher than the actual amount of plus 0.1-inch vitrain. On the other hand, if most of the microvitrain is extremely thin banded, near 0.02-inch, then the contribution of this substance to analytical vitrain is negligible.

Profile measurement of a column of No. 6 coal bed from Franklin County (Table 2) provided a value of 18.8 percent for vitrain more than 0.02-inch wide, of which 25 percent was less than 0.1 inch wide. This would seem to indicate the possibility that the same coal in broken form would contain 33 percent more analytical vitrain, if all microvitrain from 0.1- to 0.02-inch were completely freed and counted, than was present in bands 0.1-inch or more in thickness. However, the greater part of this vitrain from the microvitrain bands is in discrete particles in only the very fine sizes. Hence, if the method of crushing reduces the volume of coal present in such sizes, and if the analysis is based on counts made in the larger sizes (plus 28-mesh) and upon estimates based upon the extrapolation of the values determined from the large sizes, the amount of analytical vitrain derived from the microvitrain is greatly reduced. The experimental evidence supporting this conclusion is presented below.

The original selection of 0.1-inch as the minimum band thickness of vitrain was made mainly in the belief that vitrain bands of lesser thickness would not tend to break away from the adjacent coal to an appreciable extent, at least in natural breakage from mine handling. The tests made, although not conclusive, bear out the assumption.

In the sizes below 28-mesh the amount of microvitrain on a weight basis was small, yet was undoubtedly of increasing importance in the vitrain content of each decreasing screen size. Obviously the correct evaluation of the actual vitrain content in these fine sizes cannot depend upon manual separation and count because of the impossibility of differentiating vitrain and microvitrain. Investigation of size-frequency distribution of vitrain, clarain, durain, and microvitrain, when crushed to a desired size and screened in a standard manner, gave information which led to the use of extrapolated curves as probably the best method of estimating the vitrain content of the fine sieve sizes. The development of this procedure is described in the section on petrographic analysis of some prepared stoker coals.

The present studies may give vitrain values a little less than would have resulted from using a lower minimum vitrain thickness, but the objective was accomplished by providing information on the approximate relative amount of vitrain in each of the 14 samples of coal examined. Corresponding data for the different coals used provided the basis for evaluating the possible influence of vitrain on combustion characteristics of the coal. However, in general, there was no evidence of such influence.[11]

Determination of Fusain Content.—Fusain does not behave in crushing with the same degree of conformity as do the other ingredients, and its quantity therefore cannot be determined by the use of the extrapolated curves.

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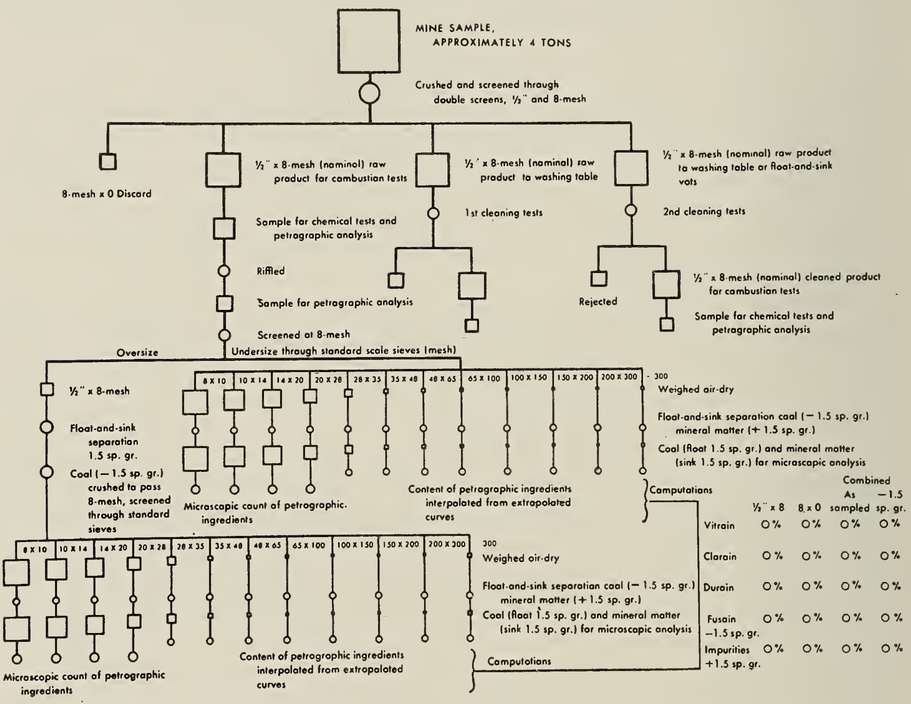
[11] Helfinstine, R. J., and Boley, C. C., Correlation of domestic stoker combustion with laboratory tests and types of fuels. II. Combustion tests and preparation studies of representative Illinois coals: Illinois Geol. Survey Rept. Inv. 120, 1946.

There are generally two varieties, sometimes called hard and soft fusain. Even the hard type is apt to be much softer than vitrain. Also, as fusain is more or less mineralized, a considerable portion of it sinks in organic solutions of 1.5 specific gravity. Therefore fusain was determined by count for each screen size and was considered to represent only the minus 1.5 specific gravity fusain of the original.


MINE SAMPLE,
APPROXIMATELY 4 TONS
Crushed and screened through double screens, ½" and 8-mesh
8-mesh x 0 Discard
½" x 8-mesh (nominal) raw product for combustion tests
½" x 8-mesh (nominal) raw product to washing table
½" x 8-mesh (nominal) raw product to washing table or float-and-sink vats
Sample for chemical tests and petrographic analysis
1st cleaning tests
2nd cleaning tests
Riffled
Sample for petrographic analysis
Rejected
½" x 8-mesh (nominal) cleaned product for combustion tests
Sample for chemical tests and petrographic analysis
Screened at 8-mesh
Oversize
Undersize through standard scale sieves (mesh)
8 X 10
10 X 14
14 X 20
20 X 28
28 X 35
35 X 48
48 X 65
65 X 100
100 X 150
150 X 200
200 X 300
- 300
Weighed air-dry
Float-and-sink separation coal (− 1.5 sp. gr.) mineral matter (+ 1.5 sp. gr.)
Coal (float 1.5 sp. gr.) and mineral matter (sink 1.5 sp. gr.) for microscopic analysis
½" x 8-mesh
Float-and-sink separation 1.5 sp. gr.
Coal (− 1.5 sp. gr.) crushed to pass 8-mesh, screened through standard sieves
Microscopic count of petrographic ingredients
Content of petrographic ingredients interpolated from extrapolated curves
Computations
½" x 8
8 x 0
Combined As sampled
−1.5 sp. gr.
Vitrain 0% 0% 0% 0%
Clarain 0% 0% 0% 0%
Durain 0% 0% 0% 0%
Fusain −1.5 sp. gr. 0% 0% 0% 0%
Impurities +1.5 sp. gr. 0% 0% 0% 0%
8 X 10
10 X 14
14 X 20
20 X 28
28 X 35
35 X 48
48 X 65
65 X 100
100 X 150
150 X 200
200 X 300
300
Weighed air-dry
Float-and-sink separation coal (− 1.5 sp. gr.) mineral matter (+ 1.5 sp. gr.)
Coal (float 1.5 sp. gr.) and mineral matter (sink 1.5 sp. gr.) for microscopic analysis
Microscopic count of petrographic ingredients
Content of petrographic ingredients interpolated from extrapolated curves
Computations

FLOW DIAGRAM
PETROGRAPHIC ANALYSIS OF STOKER COALS

FIG. 4.

Determination of Mineral Matter Content.—Mineral matter was separated from the coal in a heavy liquid of 1.5 specific gravity (Fig. 4). A preliminary separation removed substance of considerable hardness, such as pyrite, before the first crushing. A second float-and-sink separation was made, after breaking the coal to desired sizes, in order to remove additional mineral matter. The content of the first sink was derived from partings and lenses of rock and mineral matter associated with the bed coal and included shale, bone coal, and pyrite. The refuse from the second float-and-sink separation was derived from fracture surfaces, veinlets, fine bands and lenses, and disseminated particles, all associated with lump coal; it included bone coal, calcite, pyrite, clay, kaolinite, and mineralized fusain. A more complete analysis of mineral content is possible than was practiced in this work.[12]

Particles of coal firmly attached to a mineral fragment are sometimes found in the sink material. More rarely a fragment of coal is found which, because of its weight, is assumed to contain an unusual concentration of disseminated minerals, probably pyrite, sufficient to raise the specific gravity above 1.5. The relative quantity of such coal in the sink examined in these analyses was very small and was considered of no importance. The quantity of fusain found in the sink is often a considerable proportion of this substance, depending upon the extent and character of mineralization. Perhaps a third or more of the fusain in coal is commonly heavier than 1.5 specific gravity. It has been mentioned that most of the fusain in the coals tested was removed in the laboratory preparation of mine samples.

PROCEDURE OF PETROGRAPHIC ANALYSIS.

The three essential steps in the quantitative petrographic analysis of broken coal using ore-dressing technique are sampling, sizing, and separating and counting the discrete particles of each of the ingredients in the coal.

One objective was the exploration of possible differences in stoker performance resulting from variations in coal type. Such variations would be the result of differences in the relative content of the banded ingredients, particularly vitrain, clarain, and durain. As the initial material used in the combustion tests was broken coal of small size (minus ½-inch) and its character was variously modified by preparation processes, the only known means of determining its ingredient composition or type was by some petrographic procedure.

Lot Sampling and Crushing.—The initial lots of coal were obtained from material usually designated as 1¼-inch unwashed screenings, but two lots of mine-run coal and one lot of specially prepared 7/16-inch by 10-mesh stoker coal were also obtained.

Starting with the original lot of 3 to 5 tons of coal, which was obtained without special sampling procedure, a product defined as ½-inch by 8-mesh nominal raw stoker coal (Fig. 4) was prepared by crushing and screening in the laboratory for the combustion tests. (As a rule, less than 10 percent of minus 8-mesh fines was included in the coal as burned.) During this sizing preparation, increment samples were taken until about 150 pounds were accumulated. About 40 pounds were cut out as the primary petrographic analysis sample. By passing this 40-pound sample through Jones-type riffles, about 5½ pounds were secured for the petrographic assay.

The 5½-pound sample was screened through an 8-mesh sieve to separate the undersize coal, which was set aside for separate microscopic analysis, thus providing the first lot of undersize minus 8-mesh coal. The ½-inch by 8-mesh oversize was immersed in CCl_4 solution of 1.5 specific gravity to remove by float-and-sink separation the non-coal substances, mostly mineral matter, thus arbitrarily defined on the basis of specific gravity. The minus 1.5 specific gravity coal of ½-inch by 8-mesh dimensions was crushed with a spring-type double-roll crusher equipped with attachments to reduce to a minimum the loss of material during breakage. Four passes to crush all the coal as desired were usually necessary with the rolls set at 0.093-inch, 0.075-inch, 0.050-inch, and 0.025-inch apart. Successive passes through reduced openings of the rolls were necessary to break the extremely flat pieces which pass the rolls but are retained on the square-hole sieve. The crushed product of each pass was screened on the 8-mesh sieve which has an opening 0.093-inch square. This gave a second lot of minus 8-mesh coal for microscopic analysis.

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[12] Ball, Clayton G., Mineral matter of No. 6 bed coal at West Frankfort, Franklin County, Illinois—Contributions to the study of coal: Illinois Geol. Survey Rept. Inv. 33, 1935. Sprunk, George C., and O'Donnell, H. J., Mineral matter in coal: U. S. Bur. Mines Tech. Paper 648, 1942.

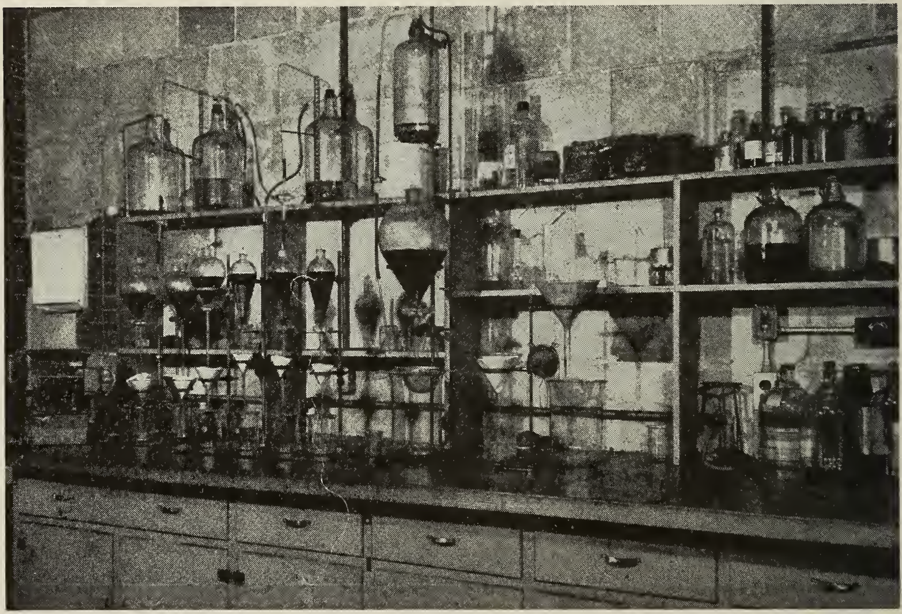


Fig. 5. Laboratory equipment for preparing samples for petrographic analysis.

Use of Roll-Type Crusher.—The roll-type crusher was used because tests demonstrated that the size-frequency distribution of the broken coal fed evenly through the roll crusher was essentially the same as resulted when coal was hand-crushed carefully with mortar and pestle (Table 3).

In making these tests, small batches of a few grams each of coal were put into a large size mortar. The large pestle was dropped of its own weight from the height of six inches for 15 consecutive times, being careful to avoid a grinding motion. The broken coal was then poured over an 8-mesh screen and the oversize returned to the mortar for further breakage. By crushing all the coal to pass 8-mesh it was believed that most bands of vitrain thicker than the minimum thickness would be resolved into discrete particles generally unattached to other coal. A few hundred grams of coal were crushed in each test and a screen analysis made.

The two lots of 8-mesh by 0 coal had undergone different stages of breakage in being reduced in size composition, and they were therefore given independent microscopic analysis. Both lots were screen-sized, using the series from 8-mesh to 300-mesh, and the screen weights were recorded.

Gravity Classification of Screen Fractions.—Each sieve fraction was immersed in CCl_4 solution of 1.5 specific gravity to remove all mineral substance freed in the crushing operations (Fig. 5). Immersion also cleaned the individual grains and facilitated identification. Two sets each of minus 1.5 specific gravity coal and plus 1.5 specific gravity mineral matter, sized and weighted, were obtained.

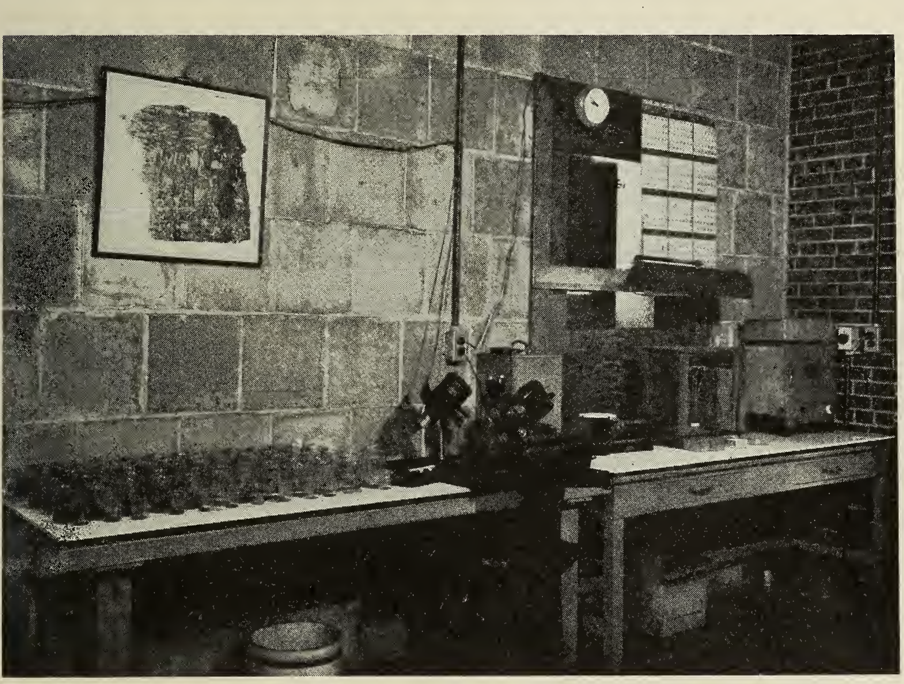


FIG. 6. Laboratory equipment used in petrographic analysis.

Separation and Counting.—The contents of each screen size were first mixed thoroughly by gentle tumbling from a full (Fig. 5) to an empty beaker. With a small flexible blade spatula, about 100 particles were obtained and distributed evenly over a cleaned and polished Petrie dish which was placed upon the microscope stage on a Greenough type ore-dressing binocular (Fig. 6). A black velvet cloth spread beneath the microscope absorbed the light transmitted through the Petrie dish.

Small dissecting needles with modified points and fine pointed tweezers were used to manipulate particles of coal and to move them out of the way when identified and counted. A Wetzlar type microscope light with a 100-watt lamp was used. This light is so made that the amount of illumination in the microscope field can be varied by adjusting the focus. Three sets of ocular lenses, 8X, 12.5X, 18X, and five objective lenses, .75X, 1X, 2X, 3X, and 6X, were used in the binocular to get the desired magnifications.

After all the particles in the first increment had been identified and counted, the procedure continued until 1,500 particles were classified and counted. This number, in a well mixed sample, proved sufficient to give percentage figures that could be duplicated within one percentage point by successive counts. Occasionally as few as 1,000 or 750 particles were counted and at the other extreme as many as 2,000 or 2,500, but a standard count of 1,500 particles was the rule (Fig. 7).

A Clay-Adams multiple laboratory counter was used in counting the particles. This is a finger manipulated, integrated counting device having five recording units and a totalizer. When 100 particles are counted a bell signal is sounded by the instrument, and at this point in the count the observer can read directly the percentage of each ingredient. This feature is a distinct advantage, for, by recording the percentages of each increment count, a continuous picture of percentage distribution is built up as the counting progresses, and the observer can tell whether or not the sample is well mixed, and how many increments it will probably be necessary to count in order to get satisfactory results.

Origin and Character of Sample Analyzed.—The coal used in the petrographic analysis consisted of samples of the ½-inch by 8-mesh material as prepared for the combustion tests. The elimination of the minus 8-mesh coal from the original sample and from the crushed oversize was not perfect, and hence the final sample may be spoken of as ½-inch by 8-mesh nominal. The sample of this coal obtained for petrographic analysis was crushed to pass an 8-mesh screen. It is apparent that this 8-mesh material came from three sources: the coal which actually was between ½-inch and 8-mesh in size, undersize coal not screened out of the original sample, and undersize coal produced from crushing of the oversize. In general it is evident that the greater part of the minus 8-mesh material used in the petrographic analysis was produced by crushing and a very small part by natural breakage.

Bases of Analytical Data.—The percentage figures for the different banded ingredients were obtained on a basis of minus 1.5 specific gravity material, since all material before analysis was subjected to float-and-sink separation in a liquid of 1.5 specific gravity. Calculation to an "as received" or "as sampled" basis was readily possible by allowing for the percentage of non-coal material rejected at 1.5 specific gravity. Percentages in the "as sampled" or "as received" form give the relative quantity of the petrographic ingredients in the stoker coals as prepared for the combustion tests.

Composition of Extremely Fine Sizes.—Most of the labor and a large part of the strain of counting the coal particles was concentrated in the very

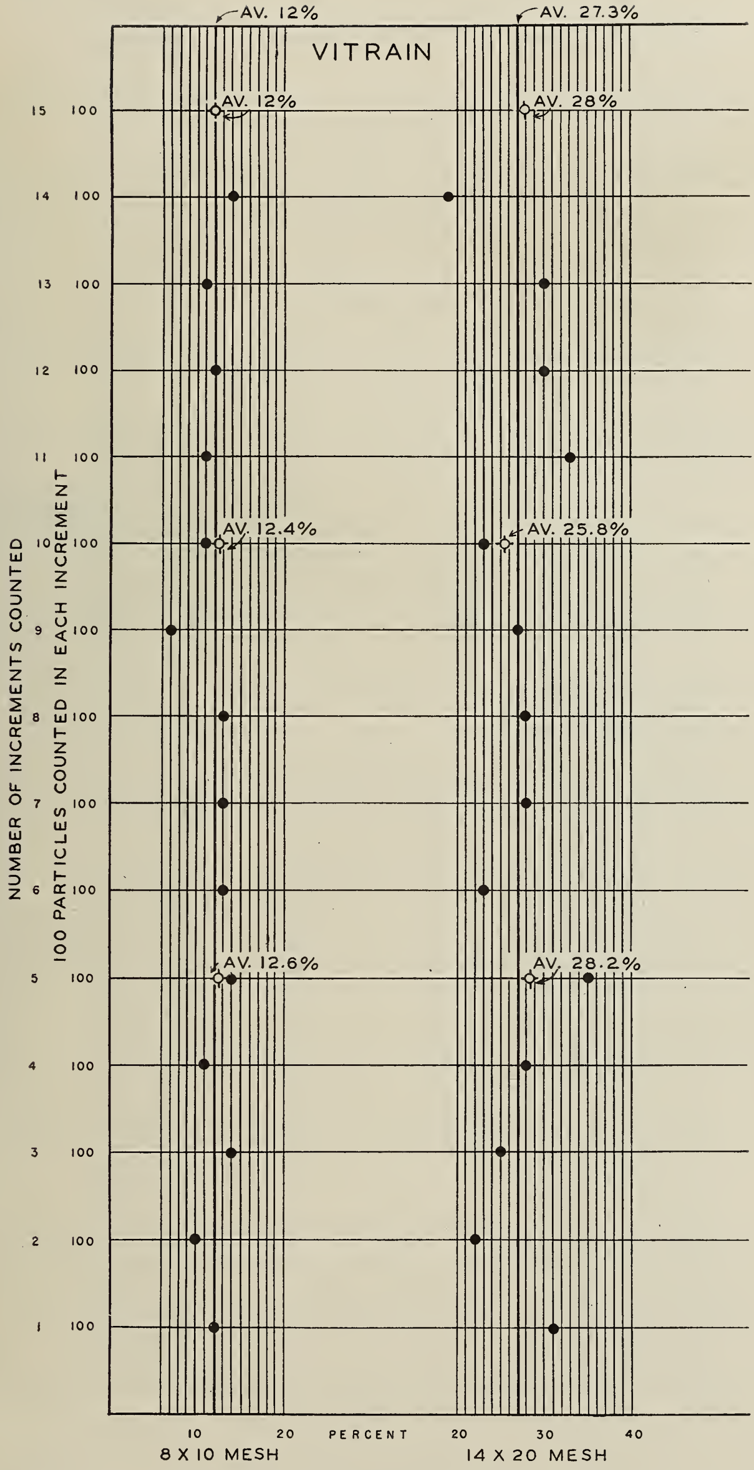


FIG. 7a. Comparison of vitrain and clarain determinations in four screen-size fractions in lots of 100 particles and of average of 500 and 1,500 particle lots.

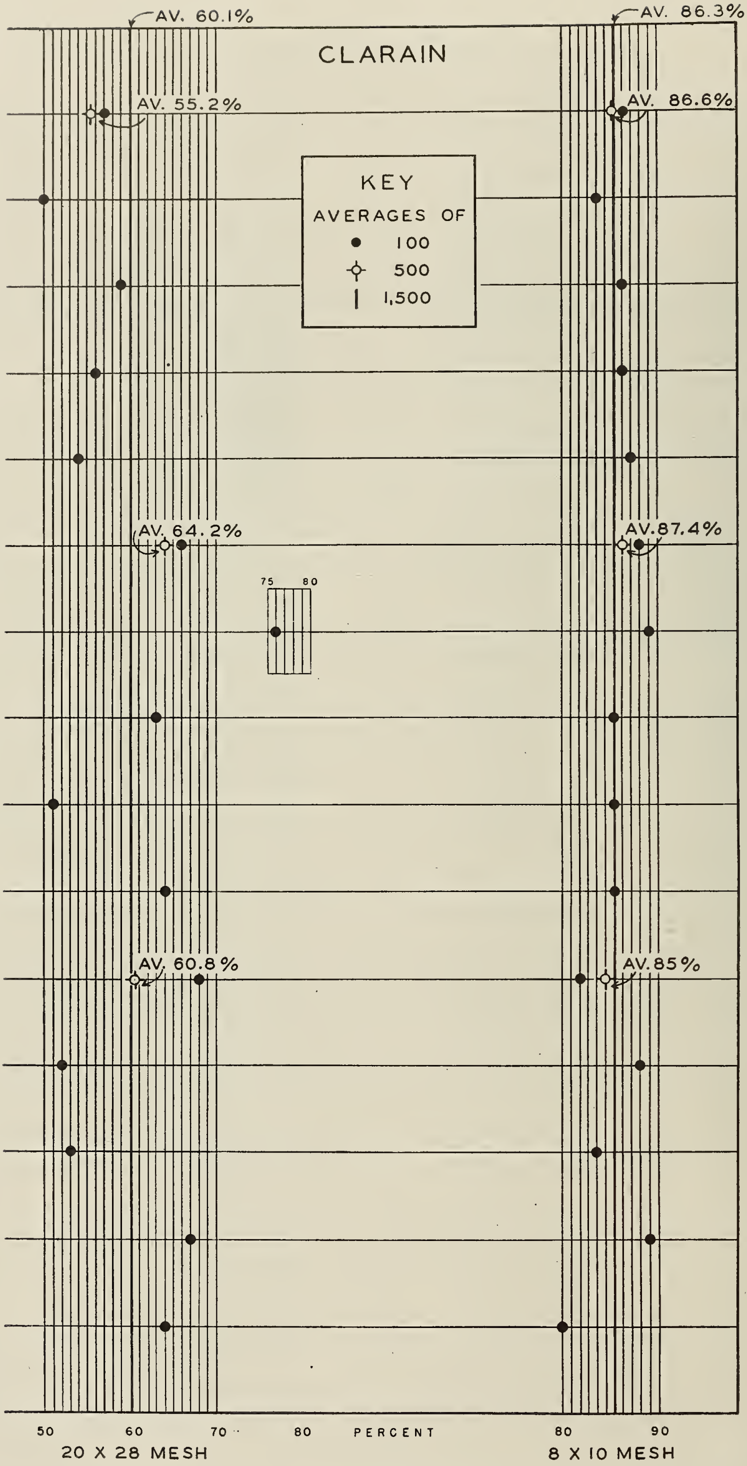


FIG. 7b (continued). Comparison of vitrain and clarain determinations in four screen-size fractions in lots of 100 particles and of average of 500 and 1,500 particle lots.

fine screen sizes below 28-mesh. It was desirable to obviate as much of this labor and strain as possible, and thereby reduce the time required for the analysis. The details of the procedure whereby the final method was developed and its validity tested are given in the section on Ingredient Distribution, but the method is briefly described here.

TABLE 5.

VITRAIN CONTENT OF A COLUMNAR SECTION OF NO. 6 COAL, FRANKLIN COUNTY, BY PROFILE ANALYSIS, AND OF BROKEN RAW AND SPECIAL STOKER COAL FROM THE SAME MINE BY SCREEN SIZES INCLUDING TABULATIONS OF THE SIZE-FREQUENCY DISTRIBUTION FOR THE BROKEN COAL.

	% Vitrain		% Vitrain
A. Columnar section, vitrain + 0.5 mm.	18.8		
B. Columnar section, vitrain + 1/10-inch	14.1		
C. 1½-inch raw screenings, vitrain + 1/10-inch	16.1		
C_1. 1½″ × ½″ (52% of C), vitrain + 1/10-inch	12.3	Floated 24% of C_1	15.7
C_2. ½″ × 8 mesh (35% of C), vitrain + 1/10-inch	18.0	Floated 24% of C_2	28.7
C_3. 8m × 0 (13% of C), vitrain + 1/10-inch	25.9	Floated 12% of C_3	57.9
C_4. 8m × 48, vitrain + 1/10-inch	29.5	Floated 53% of C_4	39.2
D. 7/16″ × 10 M mine prepared Stoker coal, vitrain + 1/10-inch	26.5		

D_1 Size-frequency distribution of vitrain in D (above)			C_5 Size-frequency distribution of vitrain in −½″ sizes of C (above)		
Size mesh	% of sample (D)	Vitrain content %	Size mesh	% of sample (C)	Vitrain content %
7/16″×3	25.3	20.0	½″×3	15.1	18.0
3×4	24.7	24.0	3×4	7.1	20.0
4×6	22.0	27.0	4×6	5.6	22.0
6×8	14.3	30.0	6×8	4.1	25.0
8×10	6.9	32.0	8×10	3.3	27.0
10×14	3.0	37.0	10×14	2.4	28.0
14×20	1.7	42.0	14×20	1.2	31.0
20×28	0.8	43.0	20×28	0.9	34.0
28×35	0.4	43.0	28×35	0.7	30.0
35×48	0.3	43.0	35×48	0.6	23.0
48×65	0.2	38.0	48×65	0.45	22.0
65×100	0.1	25.0	65×100	0.40	16.0
100×150	−0.1	22.0	100×150	0.23	17.0
150×200	−0.1	10.0	150×200	0.24	8.0
200×300	−0.1	10.0	200×300	0.13	5.0

Investigation showed that the size-frequency distribution of hand-picked vitrain, clarain, and durain, when crushed under identical conditions, conformed essentially in terms of weight percentages retained on standard scale sieves. This discovery provided the basis for the assumption that when a *mixture* of the banded ingredients was crushed, the size-frequency distribution of the different ingredients would be essentially uniform, provided that undersized particles were readily freed from the crusher and that the grinding action of particle against particle was reduced to a minimum.

Accordingly, in order to determine the vitrain content of a suitably screen-sized sample, it was found necessary to determine the amount of vitrain present in only a few of the screen fractions and, on the basis of a curve of the same class as that representing the size distribution data for the sample as a whole, to estimate the percentage of the ingredients present in the fine screen sizes. A graph form was used, having for its horizontal scale the ratio of the standard scale sieves (Fig. 8). It is believed that greater accuracy in estimating percentages is obtained by this method than by laborious and difficult counting of the fine particles, because of the errors introduced through the appearance in the very fine sizes of increasing percentages of microvitrain derived from the clarain. The nature and extent of this error are discussed in detail in the section on Ingredient Distribution.

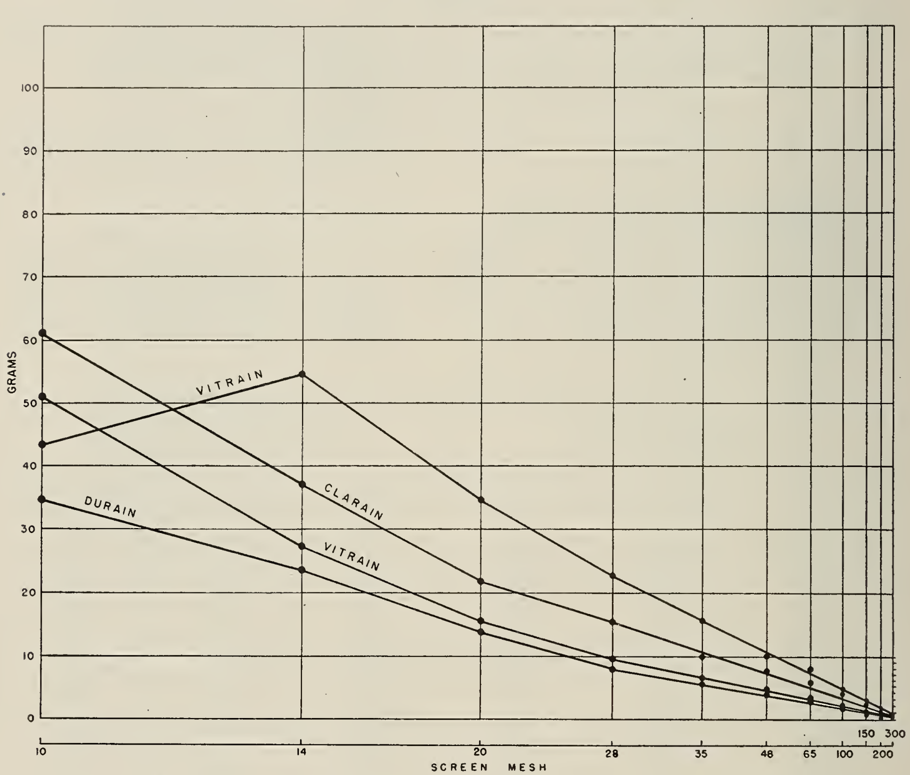


FIG. 8a. Method of extrapolating curves for fine sizes and of interpolating values for banded ingredients. True plot of weight distribution of screen fractions of selected samples of banded ingredients roll-crushed to pass 8-mesh.

PETROGRAPHIC ANALYSIS OF PREPARED STOKER COALS.

This section presents the results of the petrographic analysis of the coals used in the stoker tests as specially prepared in the laboratory by routine tabling or by float-and-sink methods.

Source of Samples.—The large lot samples procured for the preparation and combustion of domestic stoker coals came from 15 mines located in representative mining areas and included the most commonly worked coal beds in the State (Fig. 9). Fourteen of the samples represented coals of low rank bituminous B and C. One sample came from a mine in Eagle Valley that produces high volatile bituminous A coal from Harrisburg (No. 5) coal bed. Coal of this relatively high rank is found in no other mining district in the State. One of the samples was obtained from the Friendsville coal bed near Mt. Carmel, a coal bed lying near the surface in parts of Wabash County and occurring several hundred feet above the main coal-bearing level.

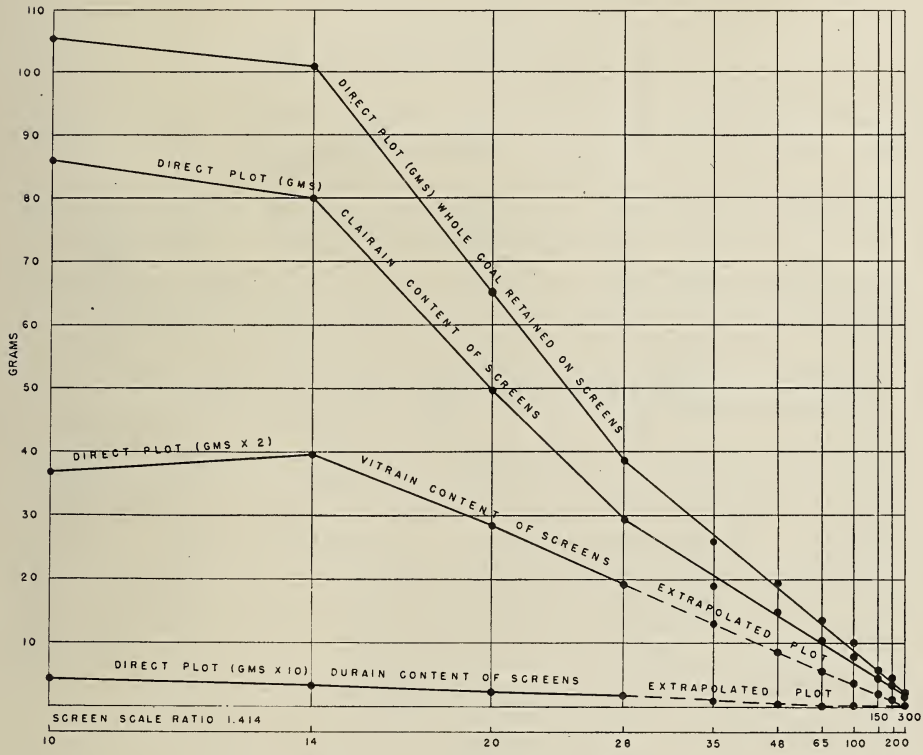


FIG. 8b (continued). Method of extrapolating curves for fine sizes and of interpolating values for banded ingredients. Plot of weight distribution of screen fractions of whole coal and of individual banded ingredients determined petrographically. Vitrain and durain determined by extrapolation below 28-mesh.

Pertinent information relating to the source of the samples is given in Table 6, and the state-wide distribution of the mine samples is shown on the accompanying map, Figure 9.

Laboratory Routine of Coal Preparation.—The 3- to 6-ton coal samples brought from the mine to the laboratory were first passed over vibrating double screens of ½-inch and 8-mesh openings, with the oversize being reduced by crushing to pass the top screen. The undersized material was discarded. The screened coal was divided into three parts, one to be used directly for combustion tests and the others to be subjected to coal cleaning processes before combustion (Fig. 4).

TABLE 6.

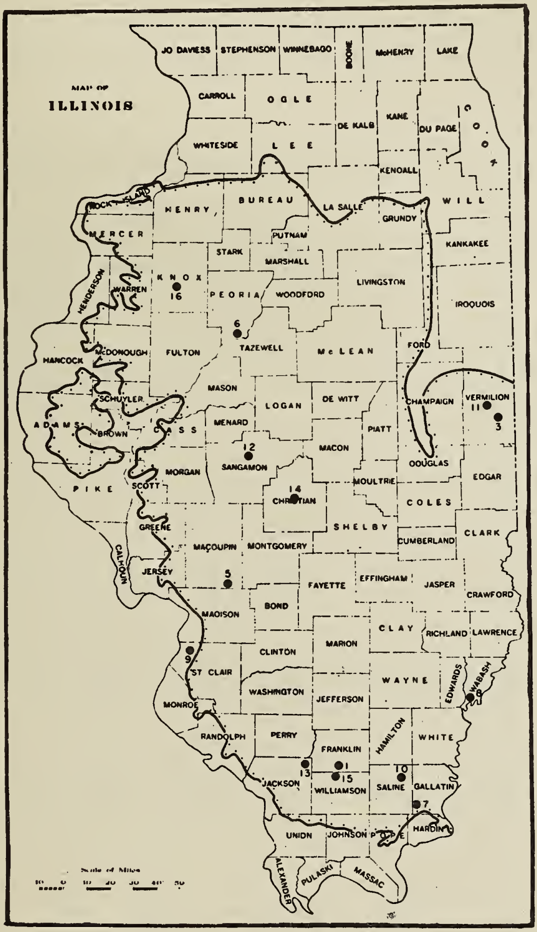
SOURCE AND DESCRIPTION OF SAMPLES.

Lab. No.	County	Coal bed	Mining district[a]	County rank index[b]	Rank, high volatile A, B, or C	Description of coal
1	Franklin	Herrin No. 6	Franklin-Williamson	131	B	Washed stoker, 7/16″ by 10-mesh
2	LaSalle	LaSalle No. 2	LaSalle	122	C	Raw 1¼″ stoker
3	Vermilion	Grape Creek	Danville	122	C	1¼″ screenings, dedusted
5	Macoupin	Herrin No. 6	Central Illinois	121	C	1¼″ screenings
6	Peoria	Springfield No. 5	Fulton-Peoria	122	C	1¼″ screenings
7	Gallatin	Harrisburg No. 5	Eagle Valley	145	A	Mine run
8	Wabash	Friendsville	Mt. Carmel	122	C	Largely 2″ or 3″ screenings with some lump
9	St. Clair	Herrin No. 6	Belleville	126	C	Mine run. Considerable fine coal included
10	Saline	Harrisburg No. 5	Saline	137	B	Stoker. 1½″ by 10-mesh
11	Vermilion	Danville No. 7	Danville	125	C	Small stoker, 1″ by 8-mesh
12	Sangamon	Springfield No. 5	Springfield	121	C	Largely stoker, 1″ by 5/16″, with some 5/16″ by 0
13	Randolph	Herrin No. 6	Southwestern Illinois	126	C	Crushed 1½″ by ¾″
14	Christian	Herrin No. 6	Central Illinois	123	C	1½″ screenings
15	Williamson	Herrin No. 6	Franklin-Williamson	133	B	1½″ dedusted screenings
16	Knox	Rock Island No. 1	Northwestern Illinois	123	C	Stoker, 1″ by ¼″

[a] Designation of mining districts approximately as used in: Bement, A., Illinois coal: Illinois Geol. Survey Bull. 56, p. 23, 1929.

[b] Average heating value expressed in hundreds of B.t.u. per pound on a moist mineral-matter-free basis, for face samples reported up to October, 1934. See: Cady, Gilbert H., Classification and selection of Illinois coals: Illinois Geol. Survey Bull. 62, 354 pp., 1935.

Effect of Routine Preparation on Vitrain Distribution.—The petrographic analyses are of special interest in connection with the combustion tests because they reveal the extent to which the coal cleaning processes affected the petrographic composition of the coal. The nature of these effects can be determined by consideration of the accompanying data (Tables 7 and 8). An increase in vitrain content is the usual but not the invariable rule. The initial average vitrain content of the raw stoker coals (excluding 1A) was 9.2 percent (10.6 percent on a minus 1.5 specific gravity basis). The average vitrain content after the first cleaning was 10.5 percent (11.1 percent, minus 1.5 specific gravity), an increase of 14 percent; and after the second cleaning 11.8 percent (12.2 percent, minus 1.5 specific gravity), an increase of 28 percent over the initial amount. On the minus 1.5 specific gravity basis the vitrain content ranged from 1.5 percent (8 A) to only 14.5 percent (15 A) in the untreated coal and was no higher than 19.2 percent in the improved coals (15 B).



DISTRIBUTION OF MINES SAMPLES

FIG. 9. Location of mines from which samples were obtained.

TABLE 7.

ANALYSES OF 40 STOKER COALS IN TERMS OF BANDED INGREDIENTS ON AN "AS FIRED" AND A MINUS 1.5 SPECIFIC GRAVITY BASIS.

Lab. No.[a]	Lab. treatment	Banded ingredients "as fired" basis						Banded ingredients −1.5 sp. gr. basis			
		Vitrain %	Clarain %	Durain %	Fusain %	+1.5 sp. gr. impur. %	Ash ch. an. %	Vitrain %	Clarain %	Durain %	Fusain %
1A	None	26.5	66.8	1.2	1.3	4.2	7.2	27.7	69.7	1.3	1.3
3A	Crushed and screened	12.8	66.9	2.0	1.1	17.2	15.0	15.5	80.8	2.4	1.3
3B	Washing table	16.3	75.2	1.9	1.2	5.4	8.0	17.2	79.5	2.0	1.3
3C	Washing table	14.2	81.1	1.3	1.0	2.4	6.7	14.6	83.1	1.3	1.0
5A	Crushed and screened	9.8	80.5	1.7	1.4	6.6	16.6	10.4	86.2	1.9	1.5
5B	Washing table	12.3	81.2	1.9	0.9	3.6	9.3	12.7	84.3	2.0	1.0
5B[1]	Washing table	13.2	79.6	1.5	0.7	5.0	8.8	13.9	83.7	1.6	0.8
6A	Crushed and screened	10.8	71.2	1.6	0.7	15.7	15.5	12.8	84.4	1.9	0.9
6B	Washing table	12.4	82.5	0.9	0.4	3.8	9.2	12.9	85.7	1.0	0.4
6B[1]	Washing table	13.4	80.7	0.9	0.6	4.4	9.6	14.0	84.4	1.0	0.6
7A	Crushed and screened	5.7	79.7	0.5	0.5	13.6	13.9	6.6	92.2	0.6	0.6
7B	Washing table	5.2	87.2	0.9	0.5	6.2	10.4	5.5	93.0	0.9	0.6
7C	Washing table	5.1	89.0	0.3	0.6	5.0	9.8	5.4	93.7	0.4	0.6
8A	Crushed and screened	1.5	75.3	1.7	0.2	21.3	20.8	1.9	95.7	2.2	0.2
8B	Washing table	1.7	84.7	1.0	0.1	12.5	13.5	1.9	96.8	1.2	0.1
8C	Washing table	1.9	87.3	2.7	0.1	8.0	11.7	2.0	95.0	2.9	0.1
9A	Crushed and screened	7.2	69.5	1.1	0.5	21.7	19.3	9.2	88.8	1.3	0.7
9B	Washing table	6.8	82.2	0.7	0.4	9.9	12.0	7.6	91.2	0.7	0.5
9C	Float-and-sink	12.3	86.5	0.4	0.3	0.3	4.9	12.4	86.9	0.4	0.3

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[a] Lab. Nos. are the same as those used in Illinois Geol. Survey Rept. Inv. 120.

TABLE 7—*Continued.*

Lab. No.	Lab. treatment	Banded ingredients "as fired" basis						Banded ingredients −1.5 sp. gr. basis			
		Vitrain %	Clarain %	Durain %	Fusain %	+1.5 sp. gr. impur. %	Ash ch. an. %	Vitrain %	Clarain %	Durain %	Fusain %
10A	Crushed and screened	14.5	74.1	3.0	1.7	6.7	9.8	15.5	79.8	3.2	1.5
10B	Washing table	17.7	76.7	1.2	0.9	3.5	7.2	18.3	79.5	1.2	1.0
10C	Washing table	17.9	78.9	1.3	0.9	1.0	6.0	18.1	79.6	1.4	0.9
11A	Crushed and screened	7.4	70.0	0.7	0.7	21.2	17.4	9.3	88.9	0.9	0.9
11B	Washing table	10.7	80.1	1.1	0.7	7.4	10.5	11.6	86.5	1.1	0.8
11C	Washing table	9.3	86.1	0.5	0.7	3.4	8.4	9.7	89.1	0.5	0.7
12A	Crushed and screened	7.9	76.7	1.0	0.7	13.7	13.9	9.1	88.9	1.2	0.8
12B	Washing table	8.2	83.0	0.9	0.7	7.2	9.9	8.9	89.4	1.0	0.7
12A[1]	Washing table	9.6	79.5	0.8	0.7	9.4	12.4	10.5	87.8	0.9	0.8
13A	Crushed and screened	8.6	72.3	1.1	0.6	17.4	15.9	10.4	87.5	1.3	0.8
13B	Washing table	8.6	80.1	1.6	0.4	9.3	11.5	9.5	88.2	1.8	0.5
13C	Washing table	11.4	81.9	1.4	0.7	4.6	9.2	11.9	85.9	1.5	0.7
14A	Crushed and screened	11.2	71.0	1.5	1.0	15.3	12.1	13.2	83.8	1.8	1.2
14B	Washing table	11.5	82.0	1.2	1.1	4.2	8.2	12.0	85.6	1.3	1.2
14C	Washing table	14.1	80.8	1.4	1.0	2.7	7.3	14.5	83.0	1.5	1.0
15A	Crushed and screened	14.5	78.4	1.2	0.5	5.4	7.9	15.3	82.8	1.3	0.6
15B	Washing table	18.1	78.3	0.7	0.7	2.2	6.9	18.5	80.0	0.8	0.7
15C	Float-and-sink	19.2	80.3	—	0.3	0.2	2.8	19.2	80.5	—	0.3
16A	Crushed and screened	7.4	76.9	2.0	0.9	12.8	11.5	8.5	88.2	2.3	1.0
16B	Washing table	9.5	84.4	1.4	0.8	3.9	8.1	9.8	87.9	1.5	0.8
16C	Float-and-sink	9.4	87.5	1.6	0.8	0.7	4.6	9.5	88.1	1.6	0.8

Comparison with Previous Analyses of Column Sample.—For 10 column samples of coal obtained from southern Illinois (Table 2) McCabe[13] reported an average vitrain content, on the basis of a minimum thickness of 0.5 mm. for vitrain, of 16.9 percent. The average vitrain content of six raw stoker coals of the present set prepared from mine screenings samples also collected from southern Illinois mines, was 13.4 percent. The fact that these mine samples did not include the minus 8-mesh material reduced somewhat the quantity of vitrain reported, and the further fact that vitrain bands between 0.1- and 0.2-inch were included in the column sample measurements gave a somewhat larger value for these than would have been obtained had the critical width been 0.1-inch. Even so, the comparisons indicate that the content of vitrain in raw untreated screenings is probably not greatly different from that of the coal in the bed.

TABLE 8.

VITRAIN CONTENT OF 13 RAW AND CLEANED STOKER COALS ARRANGED IN ORDER OF INCREASING VITRAIN CONTENT, ON THE "AS FIRED" BASIS.

Lab. No.	½″ × 8-mesh raw stoker coal Vitrain content		Lab. No.	1st cleaning, stoker coal product Vitrain content		Lab. No.	2nd cleaning, stoker coal product Vitrain content	
	As fired %	−1.5 sp. gr. %		As fired %	−1.5 sp. gr. %		As fired %	−1.5 sp. gr. %
8A	1.5	1.9	8B	1.7	1.9	8C	1.9	2.0
7A	5.7	6.6	7B	5.2	5.5	7C	5.4	5.4
9A	7.0	9.2	9B	6.8	7.6	9C	12.3	12.4
16A	7.4	8.5	16B	9.5	9.8	16C	9.4	9.5
11A	7.4	9.3	11B	10.7	11.6	11C	9.3	9.7
12A	7.9	9.1	12B	8.2	8.9	12A[1]	9.6	10.5
13A	8.6	10.4	13B	8.6	9.5	13C	11.4	11.9
5A	9.8	10.4	5B	12.3	12.7	5B[1]	13.2	13.9
6A	10.8	12.8	6B	12.4	12.9	6B[1]	13.4	14.0
14A	12.2	13.2	14B	11.5	12.0	14C	14.1	14.5
3A	12.8	15.5	3B	14.2	14.6	3C	16.3	17.2
10A	14.5	15.5	10B	17.7	18.3	10C	17.9	18.1
15A	14.5	15.3	15B	18.1	18.5	15C	19.2	19.2
Av.	9.2	10.6	Av.	10.5	11.1	Av.	11.8	12.2

Comparison of Tabling and Float-and-Sink Preparation.—The influence of preparation processes upon the ingredient contents is shown by the results obtained by preparing two coals by both concentrating table and float-and-sink methods (Table 9). In the case of coal No. 15, for which the vitrain concentration was the larger, even with a recovery of coal by the float-and-sink method of less than 50 percent, the amount of vitrain in the recovered coal was only 18.5 percent in one trial and 19.2 percent in the other. Coal No. 15 (Williamson County) is of particular interest because its vitrain content, although prepared under conditions favorable to high vitrain concentration, was actually less than the vitrain content of mine-prepared stoker coal from Franklin County (Table 7, 1A). The inference would seem to be warranted that for the coal used, even under exacting conditions of recovery such as float-and-sink, very little more concentration of vitrain is accomplished than is effected by table washing with rejects in the order of only 15 percent.

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[13] McCabe, L. C., Concentration of banded ingredients of Illinois coals by screen-sizing and washing: A.I.M.E. Tech. Paper 684, p. 6, 1936.

TABLE 9.

Comparison of Vitrain Content of Coals Cleaned by Table Washing and Float-and-Sink Separation.

As sampled basis (Coal plus impurities)				—1.5 sp. gr. coal basis (Coal less separable impurities)			
Coal	Vitrain %	Coal	Vitrain %	Coal	Vitrain %	Coal	Vitrain %
16A Raw	7.4	16A Raw	7.4	16A Raw	8.5	16A Raw	8.5
16B Washed	9.5	16C F. & S.	9.4	16B Washed	9.8	16C F. & S.	9.5
	+2.1		+2.0		+1.3		+1.0
15A Raw	14.5	15A Raw	14.5	15A Raw	15.3	15A Raw	15.3
15B Washed	18.1	15C F. & S.	19.2	15B Washed	18.5	15C F. & S.	19.2
	+3.6		+4.7		+3.2		+3.9

16A = Raw stoker coal.
16B = Stoker coal cleaned on washing table, 14.3% of 16A rejected.
16C = Stoker coal cleaned by float-and-sink, 56% of 16A rejected.
15A = Raw stoker coal.
15B = Stoker coal cleaned on washing table, 18.2% of 15A rejected.
15C = Stoker coal cleaned by float-and-sink, 53.5% of 15A rejected.

Comparison of Analyses of Column Sample and Two Varieties of Mine Samples of Fine Coal from Same Mine.—On the possibility that the composition of raw screenings (1½-inch by 0) might be somewhat different from that of the mine prepared stoker coal (7/16-inch by 10-mesh) used in the stoker tests, a study of the petrographic composition of each was made. There are assembled in the accompanying table (Table 5) vitrain percentages for the bed column (Table 2), for the mine prepared stoker coal (Table 7, 1A), for the raw 1½-inch screenings specially determined, for the four sized fractions of these screenings, and also for the float products (1.5 specific gravity) of each of the four sized products, all representing coal from the same Franklin County mine. In addition the table gives the size-frequency distribution values for vitrain for the 7/16-inch by 10-mesh mine-prepared stoker coal and the ½-inch raw screenings.

In the columnar sample the vitrain content was approximately 18.8 percent of the bed coal in this mine (Table 2). The vitrain content of other columnar sections from the same coal bed in the same general mining region is shown by Survey records to approximate the figure given here. The records also indicate that of the vitrain measured in this columnar section, 75 percent was in bands thicker than 0.1-inch and 25 percent in bands between 0.1-inch and 0.02-inch wide.

The raw 1½-inch screenings is a broken coal product estimated to represent about ⅓ of the mined coal bed. In it the vitrain content (plus 0.1-inch) by petrographic analysis was found to be 16.1 percent, an increase over that of the bed coal of only 2 percentage points or about one-seventh. Although this increase of 14 percent is an appreciable amount percentage-wise, it does not represent any notable concentration.

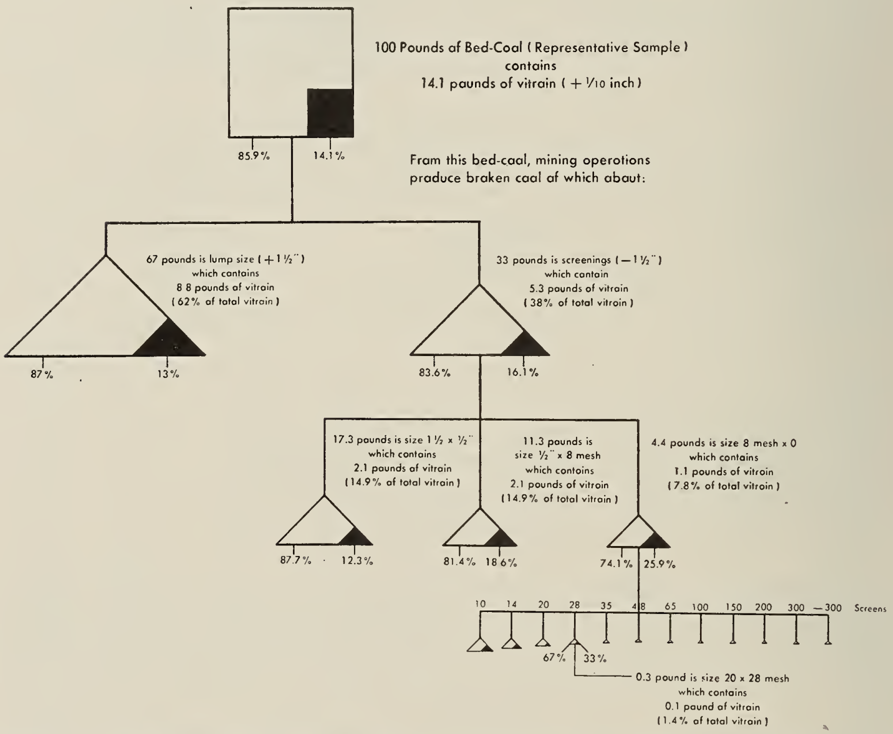

FIG. 10. Diagrammatic representation of vitrain distribution of various sizes of naturally broken coal based on petrographic analysis.

The distribution of this variation in vitrain content in terms of the size fractions was as follows: The 1½-inch by ½-inch product, consisting of 52 percent of the screenings, contained 12.3 percent vitrain, which is about 13 percent less than the bed coal. The ½-inch by 8-mesh fraction contained 18 percent vitrain, indicating a tendency toward concentration as size decreases, a tendency which results in an increase to 25.9 percent vitrain in the 8-mesh by 0 fraction. It may also be noted that by means of very rigorous gravity separation involving large reject losses, the percentages of vitrain were raised to 15.7, 28.7, and 57.9 respectively for the three size fractions. Although the vitrain content of the float 8-mesh by 0 fraction attains the high value of approximately 58 percent, the actual amount of vitrain present is only about 1 percent of the 1½-inch sample and is accomplished by a very high degree of selective concentration.

It will doubtless be observed that the vitrain content of the 7/16-inch by 10-mesh stoker coal is somewhat higher than either the ½-inch by 8-mesh or the 8-mesh by 0 fractions, which combined have a vitrain content of 20.1 percent. An analysis of the distribution of the vitrain in the various sizes of these two coals given in the two size-frequency distribution tables (Table 5) and Figure 10, together with the figures on vitrain content in the 8 by 48-mesh coal derived from 1½-inch screenings, provides an explanation for the higher content of vitrain in the prepared stoker coal. The 8 by 48-mesh fraction is essentially a dedusted coal, and it is apparent that the minus 48-mesh dust contained a considerably smaller proportion of vitrain than the 8 by 48-mesh fraction, in view of the increase in the vitrain content as a result of the elimination of the dust. Accordingly it is to be expected that the percentage of vitrain in the various screen fractions will decrease in the finer screen fractions. Thus in the ½-inch raw screenings, the maximum percentage of vitrain is contained in the 20 by 28-mesh fraction; and in the 7/16-inch by 10-mesh coal it is in the sizes 14 by 48-mesh, decreasing rapidly below in both coals.

It is apparent that the quantity of vitrain in the 1½-inch screenings is about 5 percent in excess of the proportion of this ingredient in the bed coal, as determined by column measurement. It is also apparent that this concentration is contained in the sizes ½-inch by 48-mesh. In the sizes 1½-inch by ½-inch and in the minus 48-mesh fines there is less proportional vitrain than in the bed coal. The percentage of vitrain in sizes ½-inch by 48-mesh is, by calculation, about 21 percent. It is probable that additional cleaning would raise the vitrain content in this size to approximate that of the 7/16-inch by 10-mesh mine prepared coal.

The relatively low concentration of vitrain in the improved coals used in the stoker tests, and studies of the vitrain content of specially prepared coals described above suggested the advisability of investigations into the extent and character of concentration of banded ingredients produced by float-and-sink separation. The procedure and results of such tests are described in the section on Float-and-Sink Separation.

INGREDIENT DISTRIBUTION IN SMALL SIZES OF BROKEN INGREDIENTS AND WHOLE COAL.

In the present exploration of the character of breakage of the banded ingredients of Illinois coals and the size-frequency distribution obtained, the studies sought to determine whether or not hand-picked ingredients broke similarly to coal as a whole, and whether or not the character of the breakage favored segregation of any of the ingredients in any of the screen sizes when subjected to screen separation. The manner of use of the results of the investigation in arriving at estimates of the composition of broken coal in terms of the ingredients is explained below.

Size-Frequency Distribution of Banded Ingredients and of Whole Coal.—Screen analysis was made of four varieties of coal: (1) Hand-picked vitrain, clarain, and durain (Table 3, Fig. 13); two natural coals, (2) 1½-inch by ½-inch and (3) ½-inch by 8-mesh, respectively, all being crushed mechanically or by hand to pass an 8-mesh screen; and (4) for special comparison, a sample of coal of minus 8-mesh size obtained from the undersize coals screened out of one of the samples brought to the laboratory for combustion tests.

It is apparent from a scrutiny of the data (Table 3, columns 1 to 7, and Fig. 11) that in spite of the known difference in the hardness of vitrain, clarain, and durain, the same conditions of crushing yield a similar pattern of size distribution. Furthermore, it is apparent that this pattern of size distribution is also shared in a general way by all the other coals tested.

General Law of Size Composition of Broken Coal.—The size composition of broken coal has been extensively investigated by coal research organizations, one notable contribution being the development by Rosin and Rammler[14] of an equation relating the percentage of coal retained on a test sieve to the size of the openings in the sieve. M. R. Geer and H. F. Yancey of the U. S. Bureau of Mines tested the applicability of Rosin and Rammler's law for expressing the size composition of a variety of broken coals of both coarse and fine sizes. They prepared a specially ruled graph paper by using the equation as modified by Bennett[15] to plot cumulative weight percent against screen size for a large number of screen analyses. When the size distribution of a crushed material conforms with Rosin and Rammler's law, the cumulative percentage data from screen analysis when plotted on this form of graph will show a straight line relationship (Fig. 11).

Application of the Rosin and Rammler Law to the Immediate Size-Distribution Data.—Upon the special graph form, prepared in accordance with the specifications of Geer and Yancey, the screen analysis data (Table 3) were plotted for the various coals used in this special investigation. It is apparent that the hand-picked banded ingredients as well as the mixed coal samples produce essentially straight lines (Fig. 13) and hence that the size-frequency distribution conforms with the Rosin and Rammler law. The greatest amount of variation from a straight line for any coal is found near the top size, that is the 8 by 10-mesh size. This phenomenon was noted and explained by Geer and Yancey as a peculiar attribute of the Rosin and Rammler equation which they state does not describe accurately the distribution of the coarsest particles.[16]

A deviation from a straight line also may be observed for the three finest screen sizes for every coal. This, however, is of little significance. A careful examination of the graphs will reveal that no plotted point is more than 0.5 percent removed from the straight line. Therefore, although the

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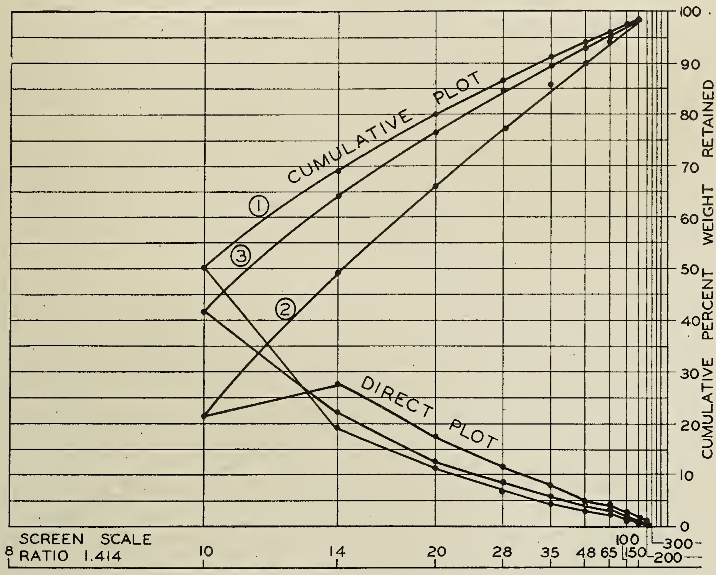
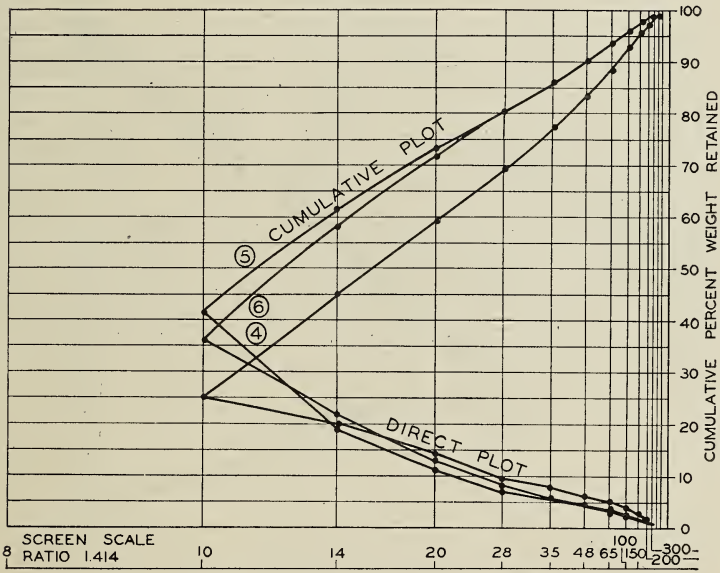
[14] Rosin, P., and Rammler, E., Laws covering the fineness of powdered coal: Inst. Fuel Jour., vol. 7, pp. 29–36, 1933.

[15] Geer, M. R., and Yancey, H. F., Expression and interpretation of the size composition of coal: A.I.M.E. Trans., vol. 130, pp. 250–269, 1938. Bennett, J. G., Broken coal: Inst. Fuel Jour., vol. 10, pp. 22–39, October, 1936.

[16] Geer, M. R., and Yancey, H. F., op. cit., p. 257.

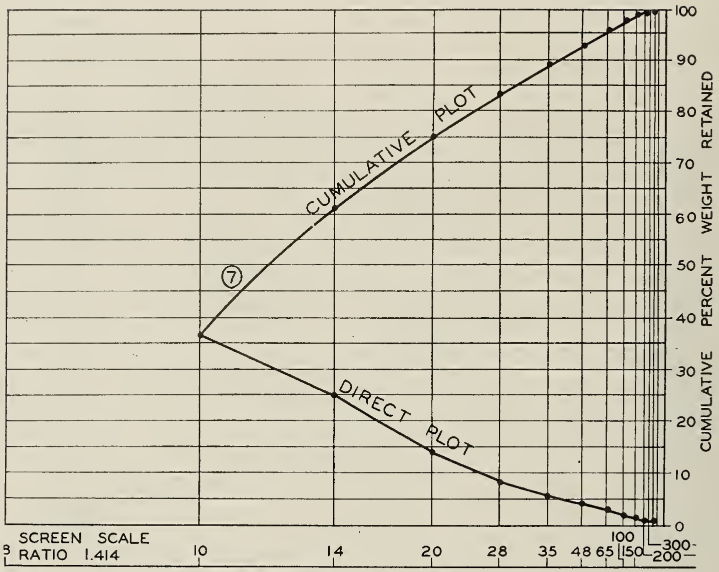


VITRAIN, COLUMNS 1, 2, 3 OF TABLE 3

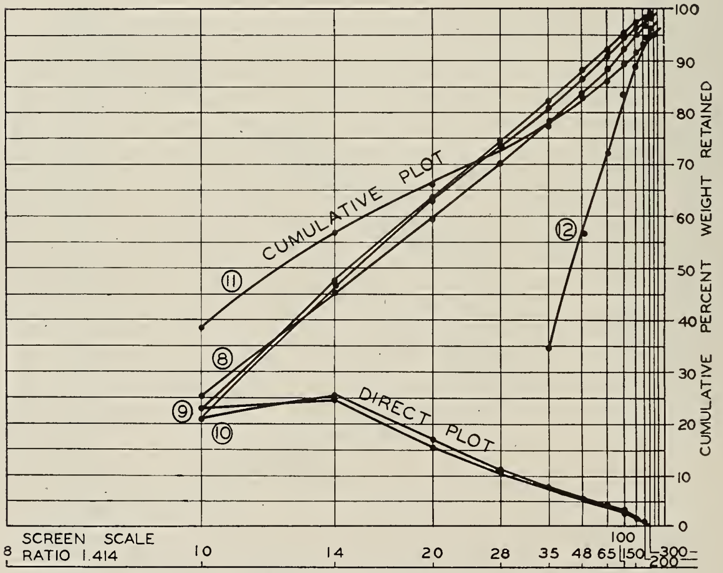


CLARAIN, COLUMNS 4, 5, 6 OF TABLE 3

Fig. 11a. Cumulative and direct plotting of screen analysis data (Table 3) with horizontal scale in same ratio as that of the standard scale sieves.



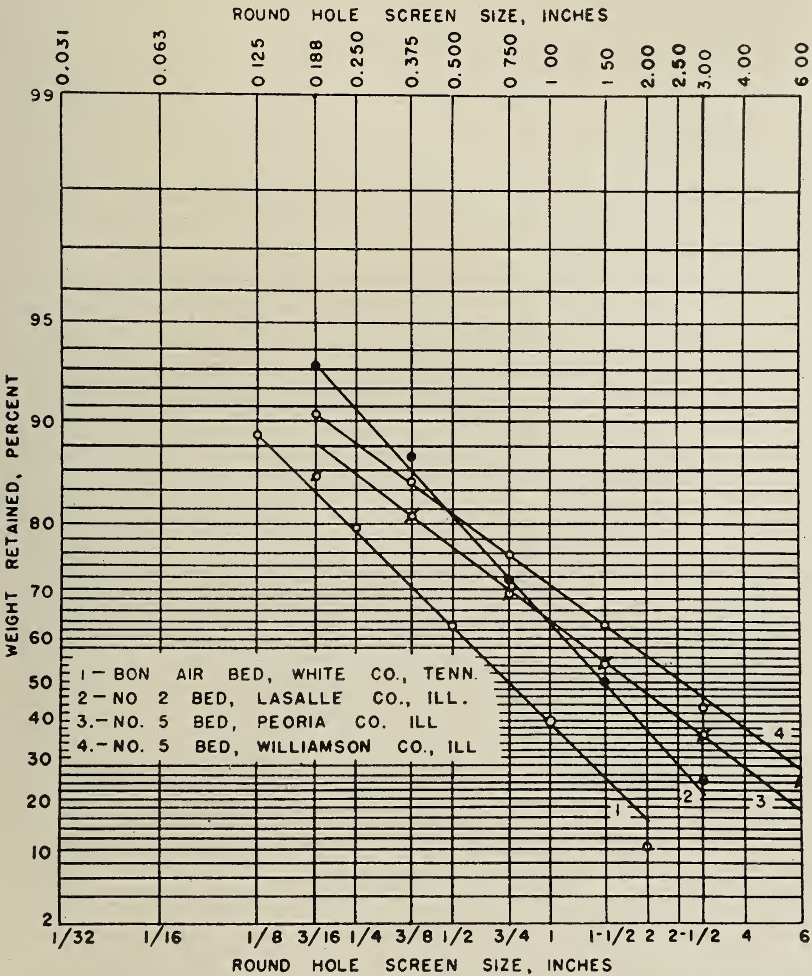
DURAIN, COLUMN 7 OF TABLE 3



MIXED COAL, COLUMNS 8, 9, 10, 11, 12 OF TABLE 3

Fig. 11b (continued). Cumulative and direct plotting of screen analysis data (Table 3) with horizontal scale in same ratio as that of the standard scale sieves.

equation does not seem to describe quite adequately the size distribution in the finest grade sizes, the relatively small degree of departure percentagewise does not invalidate the usefulness of the curves as a picture of size distribution of broken particles of coal or of the coal ingredients.



SCREEN ANALYSES OF ONE TENNESSEE AND THREE ILLINOIS COALS.

FIG. 12. (M. R. Geer and H. F. Yancey, A.I.M.E. Trans., vol. 130, fig. 1, p. 253, 1938.)

Comparison of Size-Distribution of Vitrain in Broken Coal and of Crushed Hand-Picked Vitrain.—The validity of the conclusion reached in regard to the size distribution of vitrain in broken coal is supported by a comparison of the distribution of vitrain in the various sizes of broken mixed coal and of crushed hand-picked vitrain (Fig. 13 and Table 3, column 13). The percent distribution of the vitrain in the crushed sample of mixed coal as determined petrographically is in agreement with the size distribution of the ingredient in "pure" form when all the coal is crushed in the same manner. This similarity of distribution is the basis for the method employed in determining the vitrain content of the finer screen sizes into which the samples are subdivided preparatory to petrographic analysis.

Significance of Size Distribution as Applied to Banded Ingredients.—The exploration of the nature of breakage of mixed coal and of hand-picked ingredients by laboratory tests led to the discovery that all components as a whole generally conform to a common law of size distribution. It also indicated that there had been little or no differential breakage to produce segregation of certain of the banded ingredients in the different screen sizes, except possibly in the very fine sizes.

These tests therefore indicate that in general, when coal is broken down from the bed in mining operations, differential breakage of the banded ingredients is not nearly so complete as has been supposed, except possibly as regards fusain. Consideration of the character of the material will show why this is so. Vitrain and durain rarely exceed ½-inch in thickness and hence rarely exist as discrete coarse size fragments greater than ½-inch in diameter. On the contrary, they are commonly found in large lumps of coal that consist predominantly of clarain, and the dominant ingredient of any size category of broken coal (excepting the small sizes below 28-mesh) is clarain. It is only when the coal is subjected to complete crushing below 8-mesh (1/10-inch) that the three ingredients are recognizable to any extent as discrete entities. Consequently, the size distribution pattern of naturally broken coal is the pattern of clarain. Where mining breakage, preferential or otherwise, exposes vitrain, its marked brittleness subjects the ingredient to some differential reduction, which may account for a certain degree of concentration mainly in 8 by 48-mesh sizes. However, the impression that certain small sizes, mainly in minus 1¼-inch screenings, consist predominantly of vitrain is erroneous and is probably owing to identification of bright clarain as vitrain. As most Illinois coals consist predominantly of bright clarain, it is to be expected that the fine coal will be mostly bright. In these fine sizes the differentiation of vitrain and bright clarain is difficult and requires considerable care. It is only in the very fine sizes that liberated microvitrain begins to appear in appreciable quantity.

In the mining and the subsequent handling of coal during preparation, the forces which break up coal into lumps and small fragments are not continuously applied but are variable and accidental unless some of the coal is crushed mechanically. This results in a random breakage, often called natural breakage, but whether or not it is selective in reference to the banded ingredients other than fusain is not conclusively known. In the light of present information the absence of any appreciable degree of differential concentration of clarain, vitrain, and durain in a broken coal product such as screenings may be attributed to the following factors: (1) The tendency of the ingredients, regardless of how broken, to reduce in size and conformity

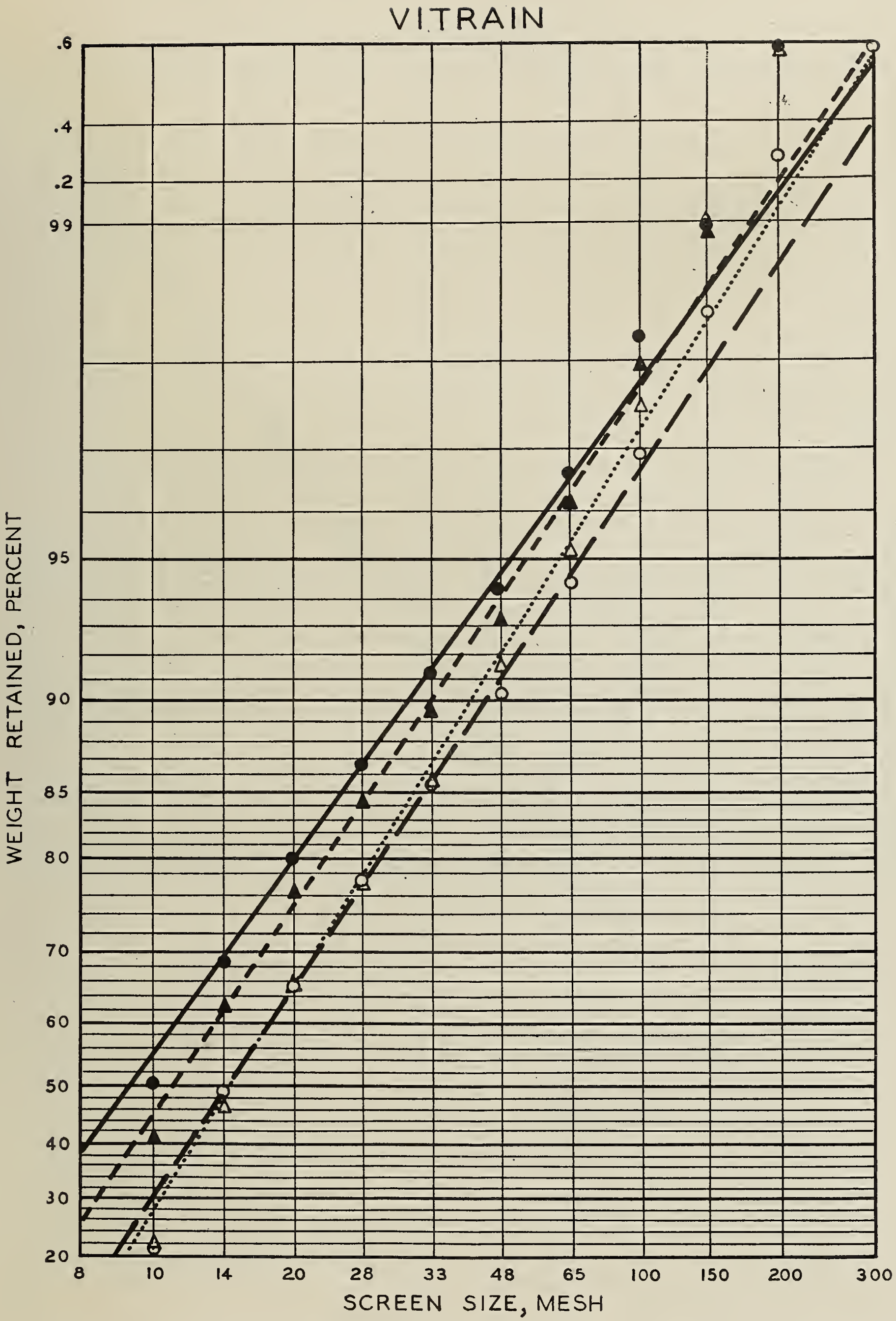


Fig. 13a. Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 1, table 3, p. 385. Open circle = column 2, table 3, p. 385. Solid triangle = column 3, table 3, p. 385. Open triangle = column 13, table 3, p. 385.

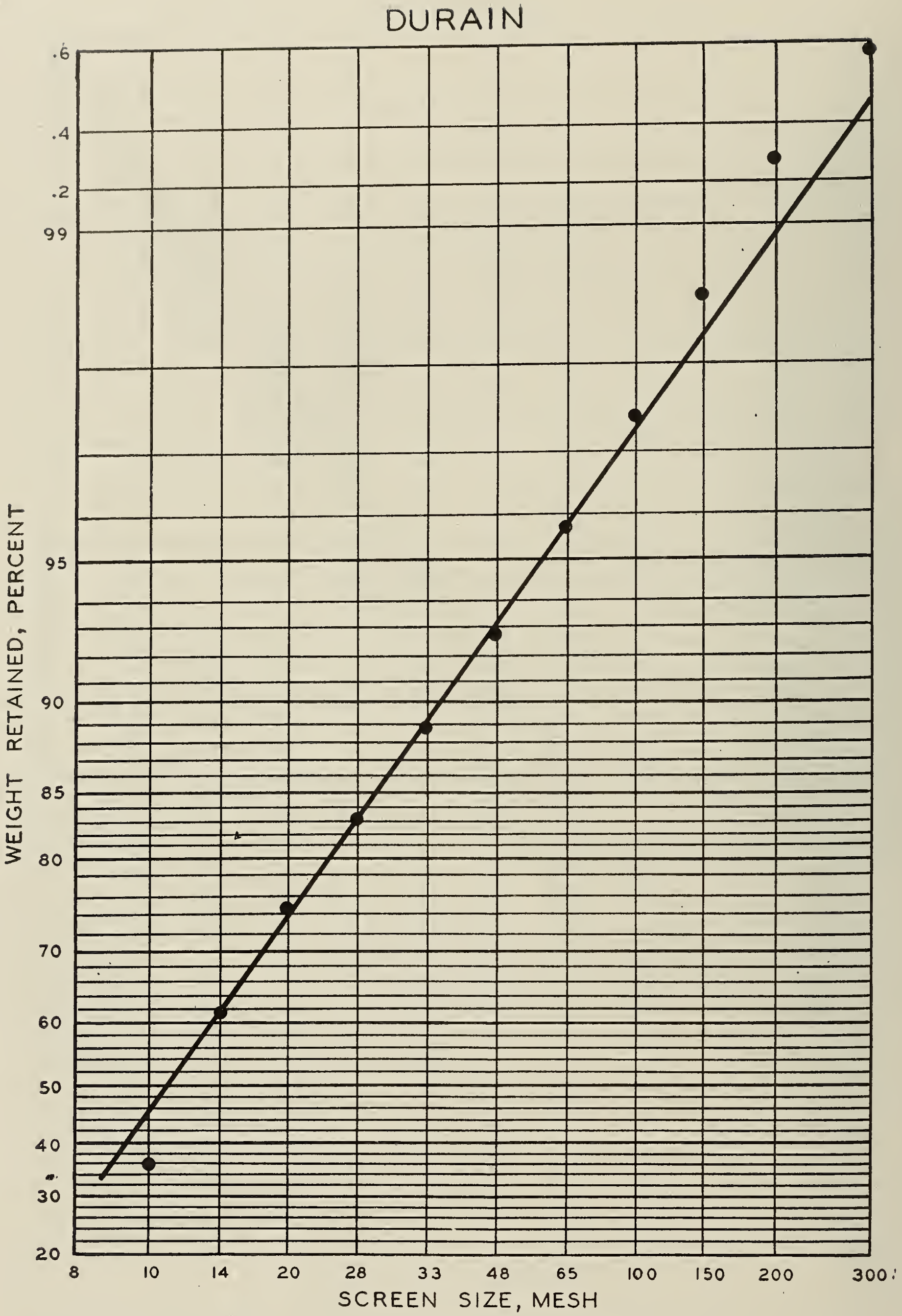


FIG. 13b (continued). Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 7, table 3, p. 385.

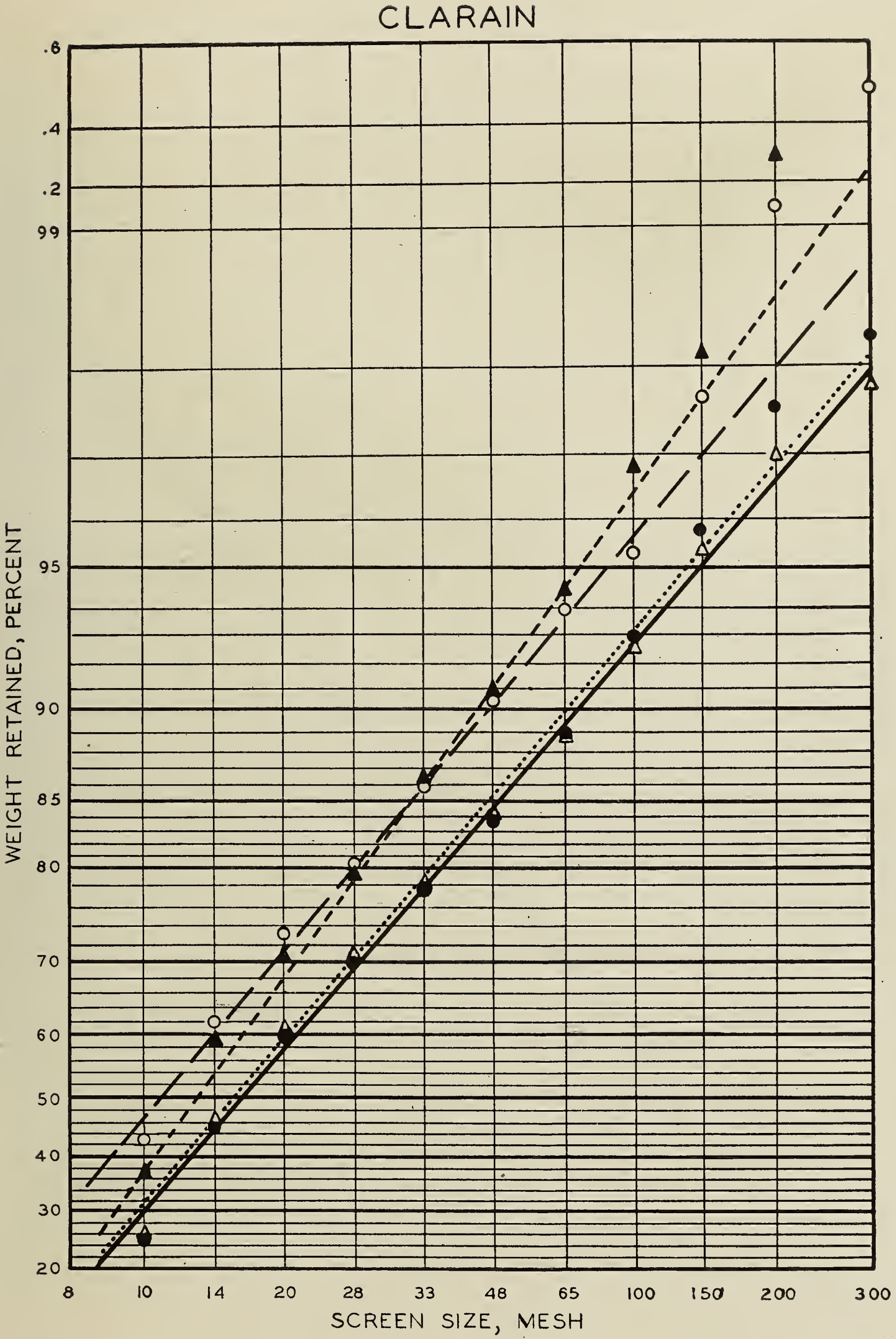


FIG. 13c (continued). Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 4, table 3, p. 385. Open circle = column 5, table 3, p. 385. Solid triangle = column 6, table 3, p. 385. Open triangle = column 8, table 3, p. 385.

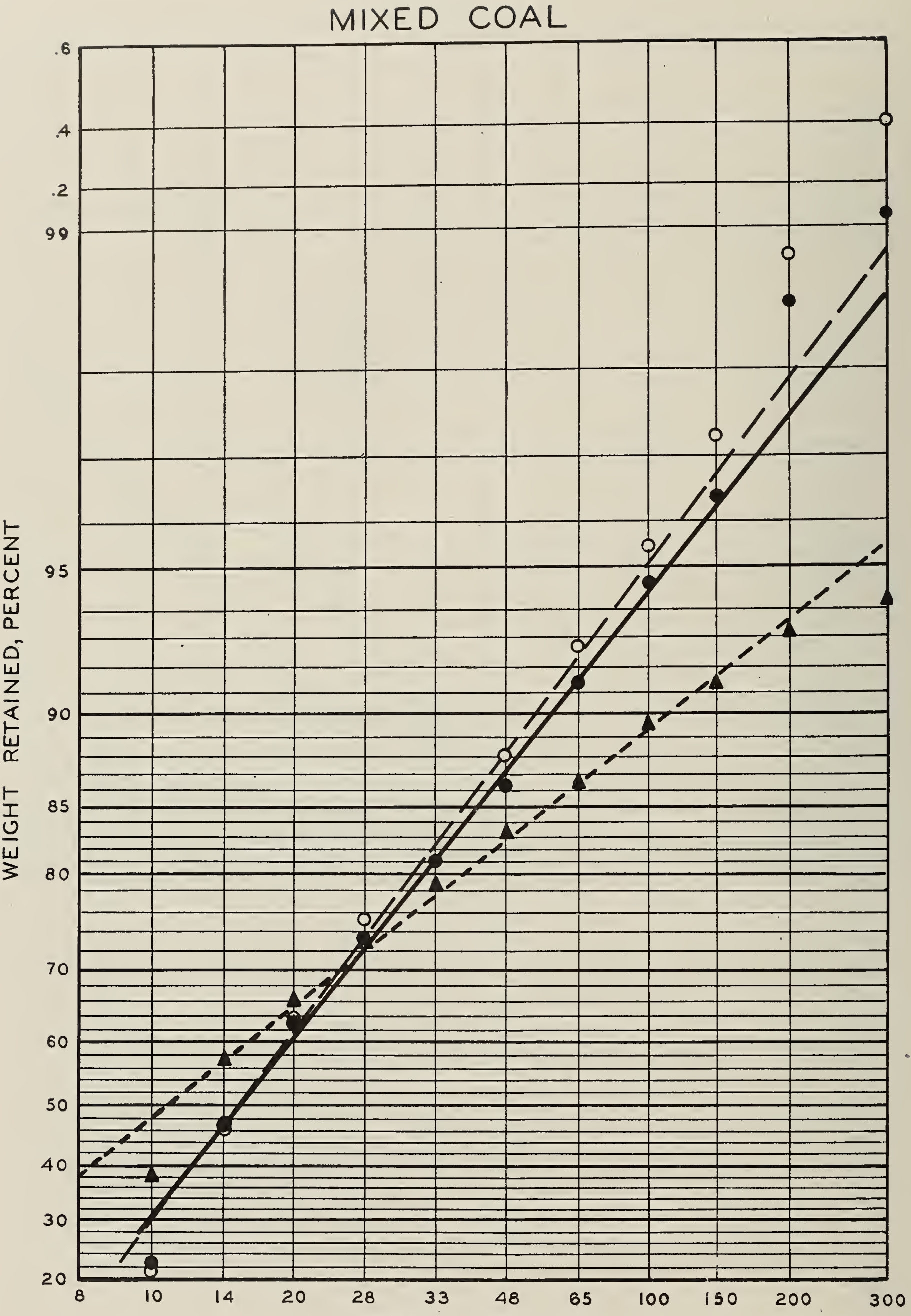


FIG. 13d (continued). Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 9, table 3, p. 385. Open circle = column 10, table 3, p. 385. Solid triangle = column 11, table 3, p. 385.

with the law of size reduction of uniformly brittle substance; (2) the relatively small amount of durain and vitrain (the two ingredients at extremes of hardness) and the thinness of these bands compared with clarain prevent important influence in coal breakage; (3) the amount of differential size reduction from abrasion and grinding of ingredients of different hardness is probably small because of the disproportionate amounts present and the discontinuous nature of the forces breaking coal in mining operations; (4) in natural breakage (mining and preparation exclusive of mechanical crushing) less than 5 per cent of the bed coal is reduced to small particle sizes (minus 8-mesh or 1/10-inch), and tests indicate a vitrain content less than 30 percent. Although this figure may be percentagewise more than twice the vitrain value in the bed coal, on a properly weighted basis, obviously very little excess concentration is possible.

EXPERIMENTAL TESTS IN FLOAT-AND-SINK SEPARATION FOR CONCENTRATING THE BANDED INGREDIENTS.

Nature of Specific Gravity of Coal.—Coal, as a porous solid substance, gives two limiting values for specific gravity. The larger value, and the true specific gravity, pertains to the coal substance and its included mineral matter less all voids; the smaller value, an apparent specific gravity, corresponds to the solid substance including the pore-spaces. The specific gravity of a lump of coal varies as the proportion of air and moisture changes in the pore-spaces. In consideration of this variability, the term "apparent specific gravity" is commonly applied to coal, and loss of moisture by drying is recognized as the most important factor in altering the apparent specific gravity.

Coal in the bed before mining is generally considered to be saturated with moisture, and if no gas is included in the pore-spaces the coal is considered near its maximum specific gravity value. Reduction of the coal to lump and smaller sizes and exposure to air during mining and handling causes changes whereby every particle of coal has a different apparent specific gravity. If any particular fragment of coal is considered, its apparent weight at any specified time depends upon the atmospheric conditions which surround it, and the weight varies between the limits of a dry and those of a saturated condition.

Close approximations to the limiting specific gravity values can be obtained for a fragment of coal by the use of a Westphal balance or similar instrument by weighing the coal air-dry, instantly under water, and again under water when the coal has become completely saturated. These three weighings permit the determination of an initial apparent specific gravity (dry basis) and a final value (saturated basis).

There are three inherent factors important in predetermining the apparent specific gravity of a particle of coal: The real specific gravity of the coal substance itself, the mineral matter content, and the porosity. It is generally conceded that vitrain is usually lower in mineral matter (ash) and higher in porosity than the other coal ingredients. Therefore in a dry condition it should be the lightest, followed in order by clarain, durain, and fusain.

It is logical to assume that the differences in apparent specific gravities of the banded ingredients (moisture-free condition) can be used to separate these components from a mixed sample by using heavy liquids. Our laboratory experiments have proved that this can be done under carefully controlled conditions.

There is a fourth factor, size of the coal particle, although not fully evaluated, which may also affect the apparent specific gravities of broken coal. The apparent specific gravity tends to increase with decreasing size of particle. A fragment of vitrain of 10 grams weight, dry basis, that will just float on a fluid of 1.250 specific gravity, when broken down into particles all much smaller than the original lump, will not float completely on the same fluid. There may be several reasons for this behavior. The larger fragments may contain air pockets in incipient fractures, giving greater buoyancy, and many have a lower ratio of mineral matter to coal and pore-spaces because of the unequal dissemination of mineral matter in the coal. Also, as the ratio of surface to volume is greater for small particles than for larger, the rate of saturation of the immersion fluid in the former may be considerably greater. In the case of durain, which is wholly attrital in nature, and of clarain, which is partly so, the difference in specific gravities of the disseminated botanical components may also affect the apparent specific gravity of the smaller particles of these coal ingredients.

Methods and Results of Experimental Tests.—The preceding explanation of the nature of the specific gravity of coal indicates the dependence upon the extent of moisture saturation of results obtained in gravity separation of the banded ingredients. The tests demonstrated this dependence and also help to explain some of the phenomena of separation and concentration of the ingredients. The tests consisted of the determination, first, of the comparative specific gravity of the individual ingredients on an air-dried basis, and second of determinations of specific gravity for successive stages of saturation from dryness to complete saturation. The results of gravity separation tests on a set of raw screenings also demonstrate some of the phenomena of ingredient separation and concentration.

Twenty-one pieces of coal ingredients weighing from 2.2 to 8.4 grams (Table 10), equally divided among vitrain, clarain, and durain, were carefully selected for purity. The specific gravity of each fragment was obtained by using a Westphal balance in the following manner. The small lump of coal having been dried to constant weight in air was then quickly weighed in distilled water. From the two weighings in air and in water the apparent specific gravity was computed with the formula of the usual type, $D = W/W - ws$. The coal was left submerged in the water until a constant weight of saturation was reached, with weights being taken at regular intervals. The accumulated data, when plotted on a graph, showed change in the weight of the coal fragment soaked in water per unit of elapsed time.

The initial specific gravities of all specimens of vitrain (Table 10, column 1) were found to be lower than those of clarain, but with only slight difference between the heaviest vitrain and the lightest clarain specimen. Had a larger number of pieces of each material been used no doubt actual overlap would

TABLE 10.

VARIATION IN APPARENT SPECIFIC GRAVITY WITH CHANGES IN MOISTURE CONTENT OF SELECTED SAMPLES OF VITRAIN, CLARAIN, AND DURAIN AS ARRANGED IN ORDER OF INCREASING SPECIFIC GRAVITY.

(1)		(2)		(3)		(4)	
Initial sp. gr.	Air dry	Soak 30 min. in H_2O		Soak 1 hr. in H_2O		Saturated condition	
gms	sp. gr.	gms	sp. gr.	gms	sp. gr.	gms	sp. gr.
V 2.198	1.131	V 2.198	1.212	V 5.550	1.235	V 5.550	1.319
V 2.553	1.164	V 5.550	1.219	V 2.198	1.242	C 6.257	1.333
V 2.115	1.176	V 4.715	1.224	V 2.553	1.247	C 8.367	1.340
V 5.550	1.176	V 3.377	1.238	V 3.377	1.257	C 5.755	1.342
V 3.377	1.187	V 4.715	1.244	V 4.715	1.262	V 4.715	1.347
V 2.940	1.195	C 5.118	1.260	C 5.118	1.279	C 5.907	1.351
V 4.715	1.200	C 5.216	1.261	C 6.257	1.282	D 5.977	1.355
C 5.216	1.204	C 6.257	1.262	C 5.216	1.289	V 2.115	1.365
C 5.755	1.206	C 2.580	1.268	C 5.755	1.291	V 3.377	1.368
C 8.367	1.213	C 8.367	1.268	C 8.367	1.291	D 5.014	1.368
C 5.907	1.215	V 2.940	1.270	V 2.115	1.303	D 5.282	1.377
C 5.118	1.218	C 5.755	1.272	C 5.907	1.318	D 3.087	1.380
C 6.257	1.221	C 5.907	1.276	V 2.940	1.321	D 2.267	1.385
C 2.580	1.223	V 2.115	1.277	D 5.977	1.327	D 6.650	1.385
D 5.282	1.275	D 5.977	1.322	C 2.580	1.330	D 6.810	1.386
D 6.810	1.290	D 5.282	1.325	D 5.014	1.332	V 2.940	1.410
D 6.650	1.293	D 5.014	1.325	D 5.282	1.338		
D 5.014	1.298	D 6.810	1.330	D 6.810	1.339		
D 5.977	1.299	D 3.087	1.332	D 2.267	1.342		
D 3.087	1.304	D 6.650	1.335	D 6.650	1.342		
D 2.267	1.309	D 2.267	1.336	D 3.087	1.343		

(1a)		(2b)		(3c)		(4d)	
Av. sp. gr.	Diff. from Vitrain	Av. sp. gr.	Diff. from Vitrain	Av. sp. gr.	Diff. from Vitrain	Sp. gr.	Diff. from Vitrain
V 1.175	—	1.241	—	1.267	—	1.362	—
C 1.214	3.3%	1.267	2.1%	1.287	1.6%	1.342	−1.5%
D 1.295	10.2%	1.329	7.1%	1.338	5.6%	1.377	1.1%

The increase in specific gravity of 4d over 1a is 15.9 percent for vitrain, 10.5 percent for clarain, and 6.3 percent for durain.

have been realized. The lighest particle of durain is at a considerable spread from the heaviest piece of clarain, so that the probability of actual overlap is less definitely indicated. The range of initial specific gravities for the vitrain specimens is considerably greater than for the other two ingredients, a relationship which indicates greater porosity. This is also indicated by the summary data which shows the percentage of increase in specific gravity of the three ingredients as saturation advanced, vitrain increase being 15.9 percent, clarain 10.5 percent, and durain 6.3 percent. These figures must be regarded as indices of relative porosity. The obvious conclusion is that the fundamental coal material, irrespective of the mineral matter, has about the same specific gravity. Whether or not this is true of special concentrations of such constituents of the clarain and durain as plant spores, resins, cuticles, remains to be investigated. Fusain is probably in a category by itself, because its relative buoyancy is determined primarily by its very porous structure, a condition unrelated to internal texture which may or may not be porous. Because of its high carbon content, it is suspected that fusain has a relatively high true specific gravity, approaching that of anthracite.

Further study of the gravity data was made to determine the theoretical maximum concentration of the ingredients that might be expected under extreme conditions of separation, such as are rarely employed in practice. This would give some idea of the possibility of gravity concentration. Simple calculations showed that if a separation fluid were used of such a gravity that approximately one-fourth by weight of the coal floated (column 4, Table 10), then 27.5 percent of the float would be vitrain and 72.5 percent clarain, with no durain present. However, only 30 percent of the total amount of vitrain in column 5 would collect in the float. If the specific gravity of the fluid were increased so that approximately 50 percent of the coal floated, then the proportional distribution in the float would be 24.1 percent vitrain, 61.8 percent clarain, and 14.1 percent durain, with 54.9 percent of the total vitrain collecting in the float. These figures give some idea of the extent of concentration of the ingredients that might be expected under conditions of definitely isolated discrete fragments of fairly large size.

To determine whether or not these characteristics apply to a more or less heterogeneous mixture of coal, a large sample of raw (1½-inch by 0) Franklin County screenings was subjected to float-and-sink separation. The tests were designed to explore the effect of variations in the specific gravity of the separation fluid upon the vitrain content of the coal. The sample was sized in the laboratory by screening into four categories: 1½-inch by ½-inch, ½-inch by 8-mesh, 8-mesh by 0, and 8 by 48-mesh (Table 11). The vitrain content of each size was determined (column 3).

The lightest 24 percent of the 1½- by ½-inch was separated by manipulation of the gravity of separating fluid. This float material was found to contain 15.7 percent vitrain, or 21.6 percent proportionally more than was present in the original sample (12.3 percent). Of the total vitrain in the 1½ by ½-inch coal, 30.7 percent concentrated in this float. This proportion is essentially the same as that derived theoretically from the data provided by the tests on the manually separated banded ingredients. The fragments were relatively large, and because they had been stored in a sealed container, it is believed that they were fairly well saturated with mine moisture.

In the second size fraction, ½-inch by 8-mesh, the float, representing approximately 24 percent, contained 28.7 percent vitrain, an increase of 55 percent. The increase of vitrain percentage is rather impressive, but of the total amount of vitrain in the immersed sample only 38.3 percent was concentrated in the float. Agreement with the theoretical percentage is not as close as it was for the larger coal but is still of the same general order of magnitude, suggesting at least approximate validity.

In the 8-mesh by 0 size coal, separation was made at an extremely low gravity so that only the lightest 12 per cent of the sample was recovered. This coal showed a very sizable increase in vitrain content (57.9 percent). But even this recovery represented only 27 percent of the vitrain in the immersed sample.

The 8 by 48-mesh coal was so floated that 53 percent was recovered, containing 39.2 percent vitrain, or 71 percent of the total vitrain content of the immersed coal.

TABLE 11.

Vitrain Content of 4 Screen-Size Fractions of a Sample of 1½-inch Raw Screenings and of 8 Float-and-Sink Products of These Size Fractions.

	(1) Size fraction	(2) Per-cent of sample	(3) Vi-train per-cent	(4) Lightest 24% of A (1) floating at 1.285 sp. gr.	(5) Heaviest 76% of A (1) sinking at 1.285 sp. gr.	(6) Percent of total vitrain col. 3 in float col. 4	(7) Percent of total vitrain col. 3 in sink col. 5
A	1½″×½″	52.5	12.3	15.7% vitrain	11.3% vitrain	30.7% vitrain	69.3% vitrain
				Lightest 24% of B (1) floating at 1.281 sp. gr.	Heaviest 76% of B (1) sinking at 1.281 sp. gr.		
B	½″×8-mesh	34.3	18.0	28.7% vitrain	16.0% vitrain	38.3% vitrain	61.7% vitrain
				Lightest 12% of C (1) floating at 1.285 sp. gr.	Heaviest 88% of C (1) sinking at 1.285 sp. gr.		
C	8-mesh×0	13.2	25.9	57.9% vitrain	21.7% vitrain	26.8% vitrain	73.2% vitrain
				Lightest 53% of D (1) floating at 1.296 sp. gr.	Heaviest 47% of D (1) sinking at 1.296 sp. gr.		
D	8×48-mesh	10.2	29.5	39.2% vitrain	18.3% vitrain	70.8% vitrain	29.2% vitrain

It is apparent that one of the two finer sizes of coal, and probably both, show a vitrain recovery considerably above the theoretical possible recovery of about 30 percent and above that of the two coarser coals. The 8 by 48-mesh coal is essentially a dedusted coal, the fusain having been largely removed, so that the content of vitrain is above that which was recovered in the 8-mesh by 0 size. Furthermore, in both minus 8-mesh samples the amount of analytical vitrain was probably increased somewhat by the presence of more or less microvitrain derived from broken clarain. The clarain that remained would therefore tend to be somewhat heavier. But the chief consideration may well be that, because of the fineness, the material was more susceptible to moisture change, so that it acquired in handling a more or less air-dried condition by the time the float-and-sink procedure was applied. This seems to be the only reasonable explanation of the phenomenon of greater recovery of vitrain from the fine sizes of coal.

Suggestions Relative to the Concentration of Banded Ingredients.—From the preceding studies it is apparent that for effecting a concentration of the discrete particles of banded ingredients of the coals used in these tests, the first requirement is the mechanical crushing of the coal to a size dimension less than 1/10-inch. The specific top size depends upon the dimensional criterion adopted for delimiting the banded ingredients, particularly vitrain. If megascopic dimension for classification is used, size reduction cannot exceed a top size of about 0.02-inch. Whatever top size is accepted, crushing should be done in such a way as to produce maximum liberation of the ingredients with a minimum of extremely fine sizes.

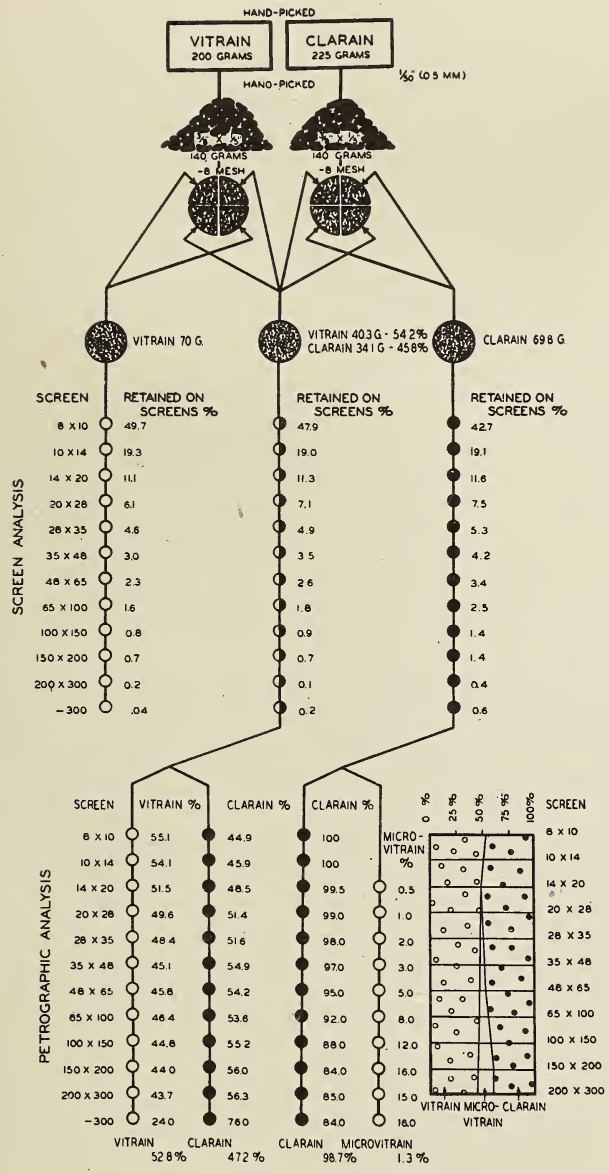
On the basis of tests demonstrating marked differences in the apparent specific gravities (dry basis) of the banded ingredients (Table 10), float-and-sink gravity separation is probably the best way to isolate the banded ingredients. Laboratory trial tests may be necessary to determine how to adjust the density of the fluid to obtain a float product containing a predominant amount of the desired ingredient. It is unlikely that a completely strict isolation of an individual ingredient can be obtained in this manner, but it seems reasonable to predict that float products can be secured containing a high concentration of such an ingredient. This has been done repeatedly in our laboratory with small samples. However, it is believed that a high order of ingredient concentration can be secured only by preparation of the coal by complete crushing to liberate the ingredients, followed by drying to bring out their maximum variation in apparent specific gravity, and by rapid separation by some form of gravity concentration. This does not preclude the possibility that methods of mining and preparing coal, other than those used in the production of the coals which were the subject of the present studies, might cause a different manner and degree of segregation of the ingredients. The possibilities of such variation have not been systematically canvassed, and further investigation is desirable.

EXPERIMENTAL COMPARISON OF PERCENTAGE ESTIMATES DERIVED BY MICROSCOPIC COUNT WITH KNOWN WEIGHT PERCENTAGES OF A MIXED SAMPLE OF VITRAIN AND CLARAIN.

It seemed advisable to compare percentage estimations obtained by petrographic analysis with the actual weight percentages of the hand-picked banded ingredients in specially prepared samples (Fig. 14).

Method and Results.—For this experiment, two blocks of hand-picked vitrain and clarain were obtained, each weighing about 200 grams. The clarain was a very finely striated variety in which the microvitrain bands were less than 0.5 mm (1/50-inch) in thickness. The specimens of vitrain and clarain were broken up separately into fragments of about ⅜ by 1/5-inch dimension and then carefully repicked to procure samples of each type that were megascopically pure. Each batch was then crushed carefully with mortar and pestle to pass an 8-mesh screen.

In preparing the sample for the microscopic count, 40.3 grams of vitrain (54.2 percent) and 34.1 grams of clarain (45.8 percent) were riffled out and



PETROGRAPHIC ANALYSIS OF A SPECIALLY PREPARED MIXED SAMPLE OF VITRAIN AND CLARAIN

FIG. 14. Diagrammatic presentation of analyses by screen sizes of hand-picked clarain and vitrain and of a mixture of the two.

thoroughly mixed. For the purpose of comparison, concurrent screen analyses were also made, using vitrain and clarain as prepared before mixing. The three screen analyses of vitrain, clarain, and the vitrain-clarain mixture are shown by the diagram (Fig. 14). It may be noted that the weight percentages retained on each screen of the vitrain-clarain mixture are intermediate between the values for the same screens for vitrain and clarain. Probably more than anything else this fact may indicate uniformity of sizing of the ingredients in both the mixed and pure samples when screened.

The microscopic assay of the vitrain-clarain mixture gave 52.8 percent vitrain and 47.2 percent clarain. These values represent an increase of 1.4 percentage points for clarain with a corresponding decrease of 1.4 percentage points for vitrain over the percentages by weight of these ingredients as mixed in the sample.

If a maximum amount of care was used in identifying and counting the coal particles in this test, the only reasonable explanation for the discrepancy in the percentage values lies in the possibility of differences in specific gravity of the vitrain and clarain used in the experiment. The percentage values which are obtained in the counting procedure are essentially volumetric estimations, and the conversion to weight percentages with screen analysis data assumes the same relative weight and volume relationship for clarain and vitrain particles. Screen analyses of the two pure ingredients classified them essentially alike with respect to size, leaving the weight relationship as the greatest uncertainty.

The best approach toward measuring the relative weights of particles of the vitrain and clarain of the same size seemed to be by actually counting and weighing a large number of particles from the same screen size of each of the reserve samples. This was done, and a total of 4,427 particles of vitrain representing 85 percent by weight of the screen size 8 by 10-mesh were counted and the average per particle weight computed to be 0.00678 gram. For the clarain, 3,054 particles were counted, representing 65 percent by weight of the screen size 8 by 10-mesh, and the per particle weight found to be 0.00637 gram.

If it be taken for granted that the weight relationship between vitrain and clarain as here determined will hold independently of particle size, then a correction of the microscopic count values to equivalent weight percentages can be made by simple arithmetic. To illustrate, let 1,000 represent the total number of all particles counted in the mixed sample to obtain the original microscopic count percentages. Then 528 (1,000 × 0.528) of the particles counted were vitrain and 472 (1,000 × 0.472) were clarain. Multiplying these numbers by the determined average particle weight of each ingredient (528 × 0.00678), (472 × 0.00637) gives 35.8 grams of vitrain and 30.1 grams of clarain, which is 54.3 percent and 45.7 percent respectively of each. These are essentially the weight percentage values of the vitrain and clarain which were combined to form the mixture.

The assumption that coal particles of like size have the same weight regardless of type of ingredient is necessary in order to convert count percentages to weight percentages, but it is evidently a source of some error.

Such an error is probably small, however, so that for practical purposes the assumption is still useful. The greater relative heaviness of the vitrain used in this experiment is probably unusual, for clarain is considered to be generally heavier than vitrain. Their difference in real specific gravity is primarily attributed to a higher ash content which clarain most often has because of its attrital composition. However, there is no fundamental reason why the mineral content of vitrain occasionally might not be such as to give it a greater relative heaviness than associated clarain.

Analysis of Microvitrain.—In order to make the experiment more complete, a percentage estimation was made of the analytical vitrain in the reserve sample of clarain. This was done by making a direct count of this material in all of the screen sizes. The result showed that the composition of the crushed clarain comprised particles of analytical vitrain to the amount of 1.3 percent of the whole sample. This raises the question as to whether this percentage of analytical vitrain introduced an error in estimating the vitrain content of the mixed sample. There can be no direct answer because there is no way of knowing how much liberated microvitrain, if any, was included in the analytical vitrain. However, the following test was made. The quantitative amounts of analytical vitrain, as determined for the four coarsest screen sizes in the mixed sample, were plotted on graph paper and the curve was extrapolated. For the remaining seven screen sizes, beginning at minus 28-mesh, the vitrain content was estimated from the curve. The vitrain content of the sample, as determined in this way, was 52.5 percent as against a value of 52.8 percent obtained by the actual count of every screen size.

Examination of the data pertaining to the amount of analytical vitrain contained in the pure clarain sample, shown in the diagram in the lower right-hand corner of Figure 14, will show that no analytical vitrain was present in the two coarsest sizes, only 0.5 percent in the third, and only 1.0 percent in the fourth. Thus there was practically no analytical vitrain in the four coarsest screen sizes. As the mixed sample was only half clarain, the amount of analytical vitrain derived from the clarain was obviously so small as to be negligible. It follows, therefore, that in extrapolating vitrain values of the mixed sample from the values in the four coarsest sizes, the analytical vitrain derived from the clarain would have essentially no influence in determining the form of the extrapolated curve. Hence the values for vitrain in the fine sizes would essentially be the values for the analytical vitrain actually derived from vitrain and would not include that derived from the microvitrain in the clarain. Therefore the interpolated value (52.5) is, at least theoretically, more accurate than the value derived by counting particles down to the finest sizes (52.8).

Conclusion.—The studies which provided the basis of this discussion were made for the purpose of having reliable information concerning the ingredient composition of the coals used in a series of combustion tests. These tests were planned to explore the correlation between combustion behavior in an underfeed type of domestic stoker and chemical attributes as determined by analyses and laboratory tests and between combustion behavior and the petrographic constitution or type of coal. There was a possibility that the data obtained might provide relatively easily determined chemical or petrographic criteria for the selection of satisfactory stoker coal. The extent and value of these correlations are discussed elsewhere.[17]

The procedure of petrographic analysis had to be developed and the analyses made while the stoker tests were in progress. Since the technique had not been critically examined, the validity of the procedure had to undergo analysis and the results had to be experimentally substantiated concurrently with the progress of the analytical work. Consequently, exploratory work was restricted very largely to the coals used in, and as prepared for, the stoker tests. The fact that earlier exploratory investigations of Illinois coal found certain fractions of broken coal with much higher vitrain content (50 to 65 percent) was realized, and this realization made it especially important that the technique employed in the present studies and the nature of the coal used should be thoroughly explained. However, the need to keep analytical work reasonably well abreast of the stoker tests made it impossible to expand the investigation into a search of the possible causes of such high percentage of segregation. Now that the technique has been developed it will be possible, and is desirable, to study systematically the effects of various kinds of breakage and coal separation, both in laboratory and in mining practice. By such procedure it will be possible to determine whether or not a high percent of ingredient segregation is possible as a result of mining and preparation practices within the range of practical usefulness.

Illinois State Geological Survey,
Urbana, Illinois,
March 6, 1949.

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[17] Helfinstine, Roy J., and Boley, C. C., op. cit.

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